

Bringing the Field into the Classroom by Using Dynamic Digital Maps to Engage Undergraduate Students in Petrology Research

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ABSTRACT

We utilize Dynamic Digital Maps (DDMs) in our undergraduate petrology courses to bring inaccessible and exciting volcanic field areas to the students in the classroom and to engage the students in research experiences. A DDM is a stand-alone computer program that presents interactive geologic maps, digital images, movies, animations, text and data (<http://ddm.geo.umass.edu>). We have developed exercises that use two different DDMs to provide field-based context for undergraduate research projects in petrology. The projects include a group research project on the evolution of the Tataro-San Pedro volcanic complex (Central Chilean Andes) and a laboratory exercise that studies magma evolution of the Springville Volcanic field (Arizona, USA). To assess the impact on student learning we administered a student assessment before and after the Tataro-San Pedro research project. We found significant gains in both students' confidence in ability to do research and to understand petrology. The DDM template is presently being converted to a cross-platform open-source format that will enable others to make their own DDMs for any field of interest. DDMs are versatile and can potentially be adapted effectively from 100-level introductory geology labs to research-oriented graduate level courses and in a variety of geologic sub-disciplines.

INTRODUCTION

Geology is a natural science with a fundamental grounding in fieldwork. The field provides a natural laboratory and is the most realistic environment in which to learn. Ideally there is no substitute for geologic fieldwork, where students make their own observations and then formulate and test their hypotheses. 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). Recent publications by national scientific organizations (e.g. NRC, 1996; NSF, 1996; NRC, 2000; AAAS, 2001) have emphasized the need for more inquiry-directed science teaching and learning in the classroom, and engaging students in authentic research experiences. Hall-Wallace and McAuliffe (2002) demonstrated that dynamic maps have the potential for improving student's skills in problem solving, analysis, and spatial visualization. Recognizing these needs, we created a way to overcome the geographic challenges and introduce 'field-based' petrology research into our courses by bringing the 'field' in the form of maps, images, and QuickTime movies to the student using Dynamic Digital Maps (DDMs) to simulate this experience. The main learning objective is to engage students in research through using the DDMs, which provide innovative access to exciting field areas and research problems. DDMs have the potential to increase

students' ability to integrate and synthesize diverse data and visualize space-time relationships.

Data for realistic field based problems can now be brought to students through use of Dynamic Digital Maps (DDMs). A Dynamic Digital Map of a particular area starts as an empty DDM-Template or program "shell" into which an author inserts information in order to enable the program to display maps, text and associated data in an organized way. Because DDMs are stand-alone programs, they need no other software (including web browsers) to present the geologic context in a much more comprehensive framework than can a hard-copy geologic map. Through links built into the software, they can conveniently present detailed high quality color maps along with field images, microphotographs, video clips, animations and analytical data. DDMs offer a variety of options to engage students in field-based research in situations where the field is not accessible. DDMs have the potential to impact student learning by reinforcing concepts through discovery, and by improving problem solving, visualization and computational skills. Investigations with DDMs allow students to identify physical and spatial relationships by constructing multiple representations of data in the form of maps, tables, and charts. Our DDMs include rock type and sample mineralogy, paleomagnetic data, major and minor element data, isotope geochemistry and geochronologic data. The DDM tools enable immediate analyses and access to visualization of large geologic multi-component data sets.

In this paper we describe how Dynamic Digital Maps (Condit, 1995a, 2000) are used as a basis for class projects in undergraduate one-semester igneous and metamorphic petrology courses, and report on the impact on student learning. These DDMs provide a simulated field experience and enable the students to use field-based information to select samples and to help formulate and test their own hypotheses on the petrologic evolution of the rocks. The main purpose was to have students actively engaged in research with essential field based grounding. The Springerville volcanic field (SVF) project (Condit, 1995b), examines an intraplate continental volcanic field. Students select a pair of lava flows based on field relations that might be related by fractional crystallization, and then to run a mass-balance model on the pair to test their hypothesis. Tataro-San Pedro (TSP) volcanic complex involves examining a Chilean subduction-zone related arc volcano. Students develop a research project to study selected aspects of the evolution of the volcano. The students conducted the projects in collaborative groups. Both DDMs include geochemical and geophysical data sets, which could be used for modeling. The DDMs described in the initial version of this paper are stand-alone programs that work only on the Macintosh platform. However, versatile, cross-platform web-enabled versions have since been developed and beta-versions of these are currently available at the URL listed at the end of the next section. The application of DDMs is not limited to the field of petrology; effective

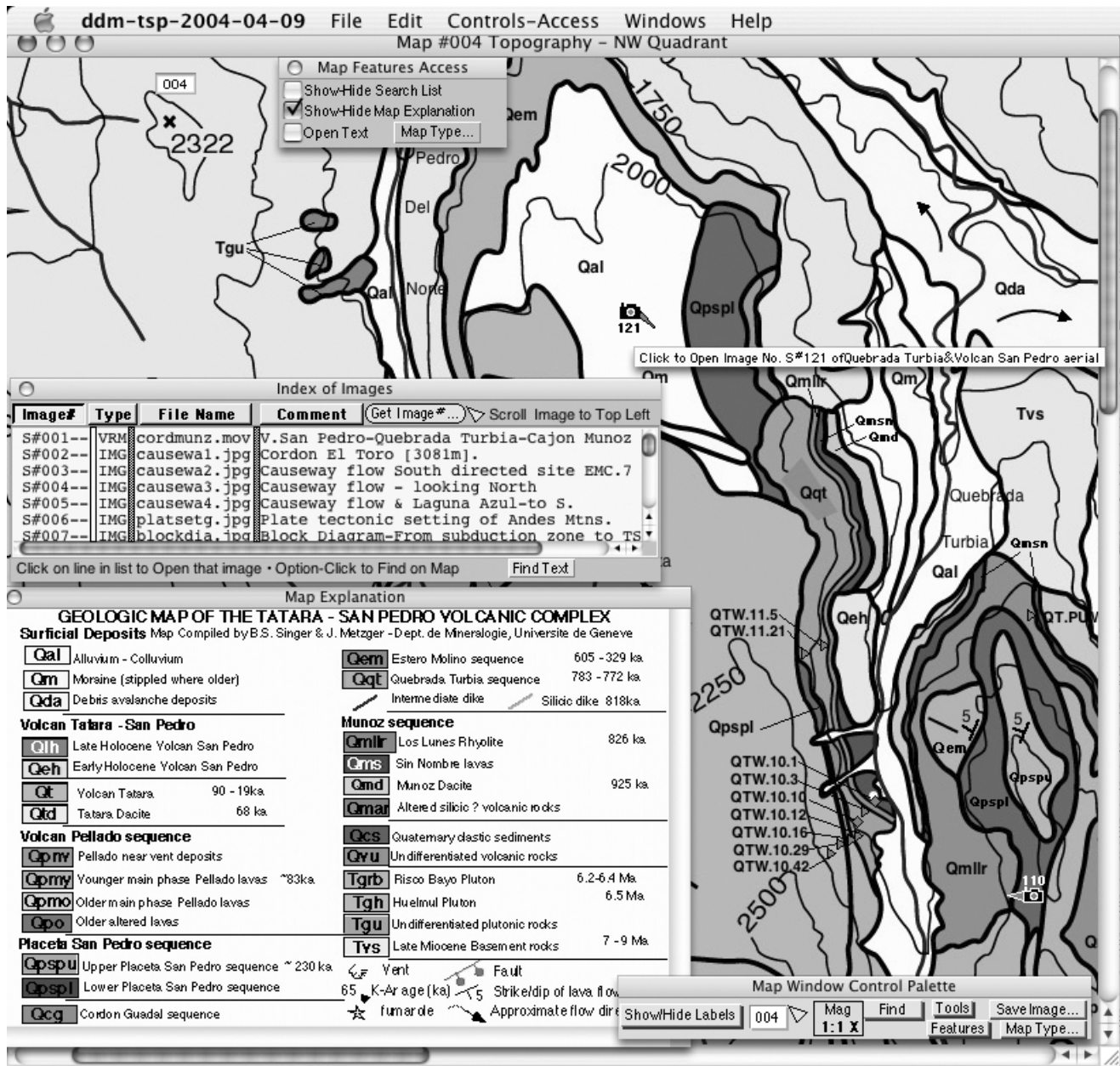


Figure 1. The DDM window display of the geologic map of the NW quadrant of the Tatra-San Pedro (TSP) volcanic complex. All sample and map symbols provide links to data; the cameras provide links to images of the areas indicated. The Index of Images provides a "table of contents" of images, and is searchable and sortable via the buttons at the top of each column. Images may be accessed by a click on the line describing each image in the list. A click on a symbol in the "Map Explanation" palette will center the map on, and locate that map unit.

projects can be developed for other sub-disciplines in geology such as geomorphology, structural geology and map-based introductory geology labs. For example, Condit (2000) presents a DDM of New England geology has been used in the introductory geology labs at University of Massachusetts-Amherst to give the students a virtual field trip of the local geology.

DYNAMIC DIGITAL MAPS: A BRIEF DESCRIPTION

A Dynamic Digital Map is a stand-alone "presentation manager" program that links maps with analytical data and digital images, movies and animations. Symbols on

the map provide links to viewing analyses, map unit descriptions, and camera icons open digital photos (Figures 1 and 2). The digital maps offer several advantages over hard-copy maps. Because the digital format, the programs can contain and instantly display much more data than found on analog maps. The data, such as digital images, movies and analytical data are linked and easily accessible. For example, field photographs can be presented at the click of a mouse. Moreover, digital maps and associated data are also more economical to produce than standard analog maps. An additional advantage is that the program contains a search routine, much like that found in a word processor that simplifies finding samples (or geologic units). The maps can be printed in color on desktop printers, or

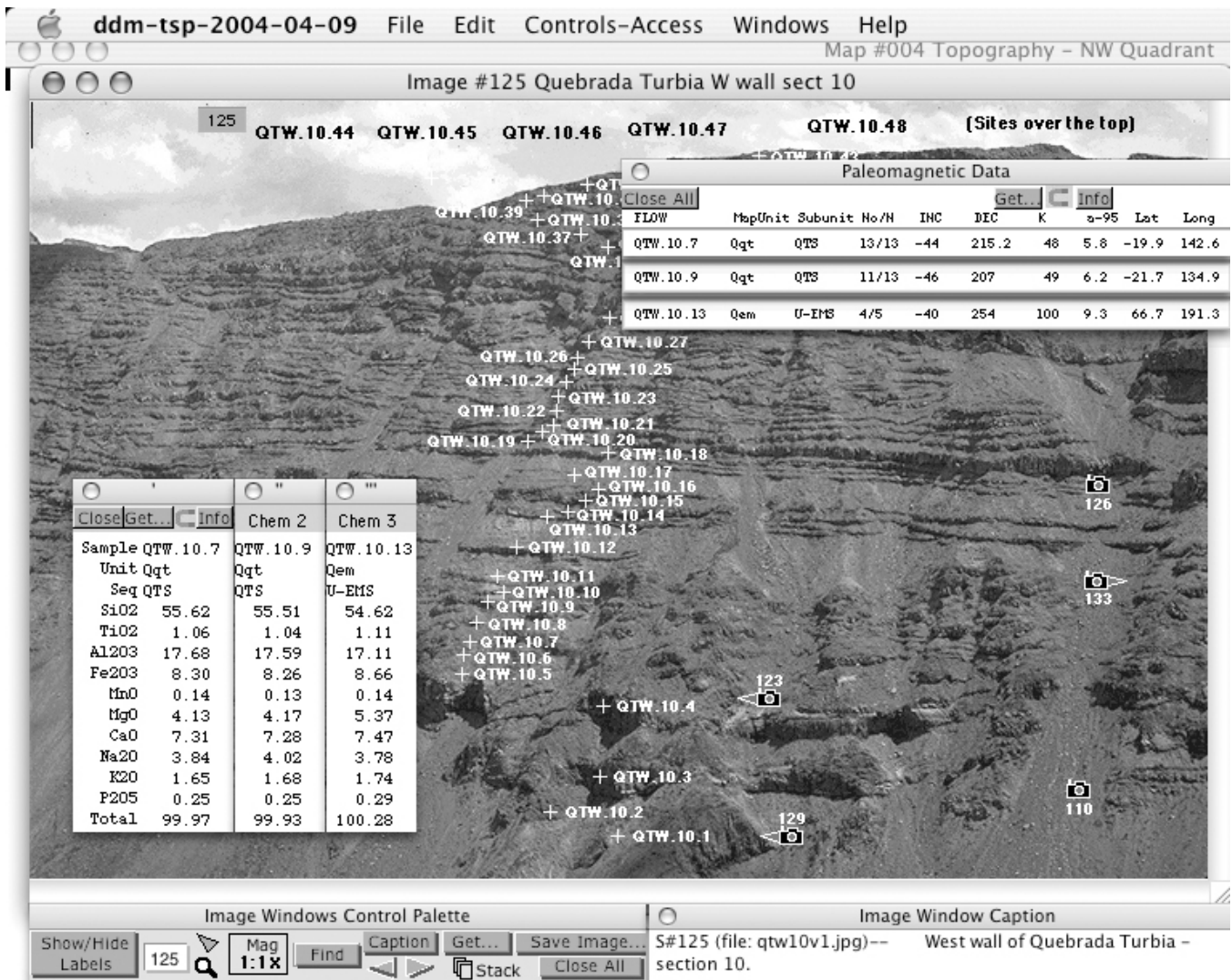


Figure 2. One of nine “Image” windows in the Tatra-San Pedro (TSP) DDM, displaying one of 193 available images. In this case the image is of the Quebrada Turbia area in the NW Quadrant of the Tatra-San Pedro map showing sample localities across a section traverse. A click on a sample site symbol on the image will display any data analyzed from that site. A click on a camera symbol brings up a field photo for the area indicated. This image is from the new cross-platform and web enabled version of the TSP DDM.

saved as separate files for import into other programs, for example computer aided drafting programs. All data can be saved from the program to tab-delimited text format, making the data easily accessible and accurately transferable to other workers.

The DDM provides several consistent ways to organize and access maps, images and data. Its home screen is an index map with outlines depicting the extent of the map that will be displayed by clicking on the outline. The home screen also provides button links to indexes with lists of various types of available data. For example, each image in the DDM is catalogued as a separate line in an “Index of Images”; the image can be displayed by clicking on its line in the list. Other “Indexes” include a one for maps, articles and various types of analytical data, providing a dynamic “Table of Contents” for the DDM. Indexes can also be displayed from Menus found at the top of the program’s screen.

Improvements now in progress will continue making the DDMs more adaptable and accessible. An essential aspect of this project includes creating a “DDM-Template” and “Cookbook” which will allow

any interested instructor or student to make their own DDM using the supplied open-source DDM-Template. Thus, a DDM project could be created and customized for any particular field area of interest. The making and modification of a DDM requires utilizing the programming environment “Revolution” (Runtime Revolution, 2004); once a DDM is created, it can be made into a stand-alone program and freely distributed, requiring no other software to run. If the person making the DDM chooses to include the source code, it can be further modified by users who have Revolution. Revolution is an object oriented, English language programming environment much like HyperCard, although it is completely cross-platform capable (Macintosh Classic, OS X, all Windows OS and 11 Unix dialects).

Progress, downloads of the DDMs and articles on this effort can be found at <http://ddm.geo.umass.edu/>. All the University of Massachusetts-Amherst and University of Wisconsin-Milwaukee class exercises, assignments and all datasets described here can be found on the this web page. The links to the UW Milwaukee

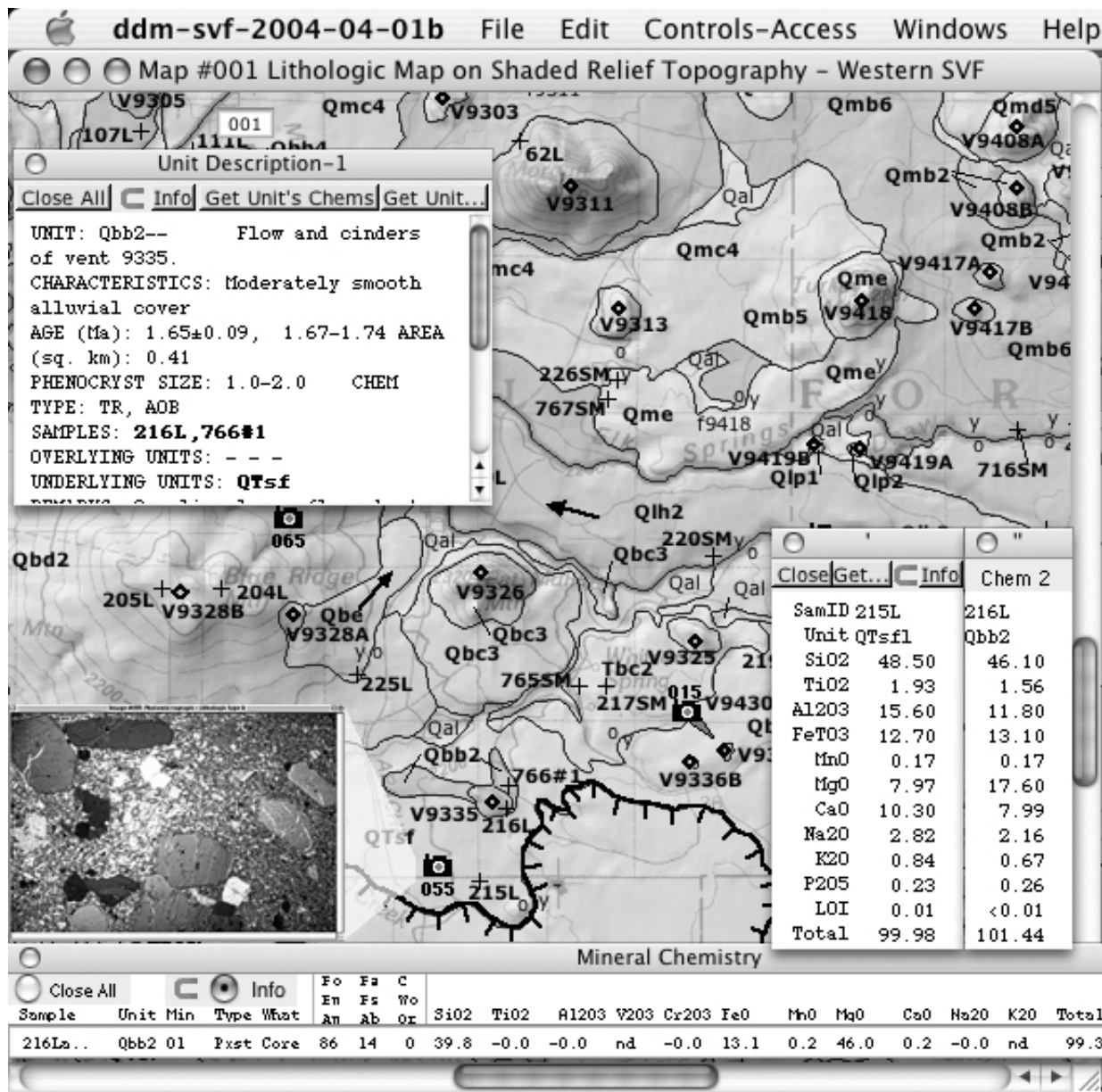


Figure 3. The DDM window display of the lithologic thematic map of the western part of the Springerville volcanic field (SVF). This map can be transformed to one of three additional thematic map types. The inset at the bottom left shows a small version of the photomicrograph that will be displayed by clicking on the camera icon labeled "055". Other features are discussed in the text.

assignments also contains rubrics to assess research projects. Cross-platform beta versions, of the Tataro-San Pedro (TSP) DDM and Springerville volcanic field (SVF) DDM, which load image and maps data via internet links can be obtained on the DDM web page (Condit, 2004).

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

Petrology Research Project in the Andes (UW Milwaukee) - The Andes Mountains where subduction is occurring along the length of the western South America are a classic area to study an active continental arc. At UW Milwaukee the students in the one-semester undergraduate igneous and metamorphic petrology course conducted petrology research in the Andes utilizing the

DDM of the Tataro-San Pedro volcanic complex (TSP) and associated database (Figures 1 and 2). One of the major course goals was to simulate a research experience for the students. The DDM's are an essential component of the research project, both in exploring field relationships and as a way to organize and utilize the data in the context of the field relationships. The Milwaukee area is "geographically challenged" with respect to access to field areas with recently active volcanoes, yet through the use of DDM's the UW Milwaukee students are able to experience "field work" on the Tataro San Pedro (TSP) volcanic complex in the Central Chilean Andes (36° S; the location and tectonic settings are show in Images 6-10 of the new TSP DDM). A detailed overview of the TSP geology can be found in Dungan et al. (2001). The TSP DDM's enable students to visualize and interpret the field relationships, for example the relationships between the

subvolcanic intrusives and the major volcano-building lavas (Figure 1). The DDM format provides spatial data for easy access and comparison, which is one of the advantages over hard-copy maps. Students used their own "DDM observations" in conjunction with other data available from the maps including geochemical and paleomagnetic data (Figure 2) to explore the evolution of the volcanic complex. Field images of the sample localities provided context for the available data, which includes paleomagnetic data, major and minor element compositional data, isotope geochemistry and geochronologic data. We found that the multi-dimensional nature of the DDM's helped engage the students in the learning and encouraged them to assess their specific topic in the larger context of the development of the volcanic complex.

The TSP Project is broken down into three exercises. The first two exercises provide the lead-up to the third exercise, which is group research project. The students worked on the TSP Project during three lab periods and out of class assignments over about a three week period, the last two weeks of which concentrated on a collaborative research project, each with three students. All the UW Milwaukee assignments along with links to additional data used for the project are available at the DDM web site. Links to examples of rubrics to assess research posters are also available on this site. The first part of the TSP Project is a lab on continental-arc igneous activity in which students are introduced to the TSP DDM map and work "hands-on" with samples from the volcanic complex. Students become comfortable with the DDM format, learning how to relate sample locations with images of the outcrops and map area. Students are prompted to explore the different types of data available and learn to export the files of the maps, images and data. In one part, students are prompted to examine the geologic maps and digital field images; from these images, students are asked to deduce the cross-cutting relations of certain units. For the second component of the lab, students examine both hand specimen and thin sections of samples from the TSP volcanic complex (including the underlying intrusives). Based on their observations, students begin to make interpretations about the evolution of the volcano based on mineralogy and textures. For example, the Holocene dacite samples contain basalt inclusions. Students are prompted to examine the mineralogy and texture of these samples and begin to formulate ideas on the implications for the evolution of the Holocene lavas.

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 et al. (1997). Using the background from the article and their exploration from the DDM, the students then are asked to develop two research questions on their own aimed at understanding some aspect of the evolution of the volcano that they would like to pursue. 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. Armed with two research questions each, the students meet in their groups to discuss their ideas and then brainstorm to decide on which research questions they will pursue together for the research project, which is the third part of the TSP project. The groups sketch out an action plan delineating 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. The action plan helps the students stay on track and serves as a guide when the student self-evaluates his or her contribution to project.

The third part of the TSP Project is the group research project in which the students implement their research planned out in the second part of the project. In conducting the research students used the geologic maps, field images, and analytical data, such as geochemical and paleomagnetic data, imbedded in the DDMs. Considering the time-spatial relationships from the map and field photos is an essential component of the research. 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 programs such as "IqPet", 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 trends in the major and minor element compositional data. Another group examined the development and implications of the most recent volcanic activity recorded at the complex. They explored the evolution of the Holocene basalts and basaltic andesites in relationship to earlier flows by comparing trends in the Sr isotopic ratios.

Each group's research was to culminate as a poster, such as would be presented at a Geological Society of America (GSA) or American Geophysical Union (AGU) meeting. In their 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 this poster scheme, the instructor created a rubric on how the research projects would be assessed. A rubric empowers the student with the knowledge of what is expected for each section of the poster (e.g. the introduction) and how it will be assessed. The students found it helpful to use the rubric as a guide as they developed their posters. Students used images of field relations and sample localities in the posters in addition to graphical displays of the 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 in which the instructor reviewed and commented on a rough-draft of the final poster. The groups presented their posters and discussed their research with the class. At the end of the project each student self-evaluates and reports on his or her contribution to the finished project. The posters were graded using the rubric and the individual part of the grade was based on the student's active participation during the presentation and discussion of the research and also on their own self-evaluation. The posters were placed on display outside the introductory geology lab for aspiring geology majors to peruse.

Modeling of Magma Evolution (UMass) - The Springerville Volcanic Field (SVF) is a classic example of a continental basaltic cinder-cone and flow dominated volcanic field, located in east-central Arizona (Condit et al., 1989, Condit and Connor, 1996), and a map of it was published as USGS Miscellaneous Investigation I-2431 (Condit et al., 1999). The SVF Project, which is used in our undergraduate igneous and metamorphic petrology class at the University of Massachusetts-Amherst, provides students with insights and examples of the rocks and deposits found in a continental basaltic volcanic field. When using the DDM, we typically pair

To what extent did you make gains in the following as a result of what you did in this class?	Pre-TSP project (avg)	Post-TSP project (avg)
Confidence in ability to do research	3.2	4.0
Confidence in ability to do petrology	3.1	4.0
Enthusiasm for the subject	3.3	4.5

Table 1. Assessment of learning gains resulting from the Tatará San Pedro (TSP) DDM project using a modified Student Assessment of Learning Gains (SALG) tool (Seymour, 1997).

up students, with the most computer-phobic student at the keyboard. Students are encouraged to work together, but are required to submit independent reports. The project has three stages consisting of two laboratory assignments and culminating a final report in the style of a Geology paper. From the DDM, students see how the petrologic data relates to the field, and use that information as the basis for choosing a parent-derivative pair flows on which to carry out a mass-balance calculation of fractional crystallization.

Students start with a short-answer exercise used to familiarize them with the DDM, and with the volcanic field. During this exercise, students describe what the program does in response to their actions, and the geology they see. The assignment begins with an automated six-minute "Tour" built into the DDM that shows many of its capabilities. It takes about an hour of in-lab time for this introductory assignment, although many students finish early, and browse most of the 75 associated images. This assignment, which includes a summary of the geology of the field, may be useful to any geologist wishing to become more familiar with continental basaltic volcanism.

During second assignment, the students test the possible genetic relationship between a pair of lava flows, possibly linked by fractional crystallization. Students go through an itemized step-by-step process to evaluate the proposed link. This requires applying petrologic reasoning to the information in DDM. Two programs, "IgPet" and "Mixing", were used to assess this link quantitatively. Although this in-class assignment only requires short-answers, students hand in the IgPet and Mixing plots, in preparation for their third assignment. The culmination is a final report that includes a fractional crystallization model of their own pair of flows. Students are given a check sheet to help them see which products (graphs, tables, data) are needed from each step of the assignment, and to help them visualize the final report. We discuss how the checklist might form a basis for a report outline, and how, once that outline is composed, we can produce the needed figures and tables around which to develop their model and write the final report. We also discuss report formats, and how they might vary, based on their intended audience. The final report for this class is modeled after a Geology article.

An example of how we can use SVF DDM to extract the supporting field data is shown in Figure 3. Here we use the DDM to find and assess whether two lavas are potential parent-derivative fractionation pairs. Unit Qbb₂, an olivine-rich flow (at bottom-center part of Figure 3) we hypothesize represents the late-erupted cumulate residuum (or bottom) of a magma chamber.

The composition of the rest of that magma chamber may be represented by the earlier erupted flow, unit QTsf, which lies beneath unit Qbb₂. A measurement between V9335 and 9336B, made using the tool included in the DDM, shows the flow's vents are within two km of each other. A look at the DDM's "Correlation of Map Units" suggests an overlapping age for the flows. Major-element analyses (lower left, Figure 3) show a decrease in MgO and an increase in SiO₂ from flow Qbb₂ (sample 216L) to flow QTsf (sample 215L). The image icon (numbered 055) displays large olivine phenocrysts in the resulting photomicrograph. Mineral compositions (Figure 3, bottom) show that the olivine in flow Qbb₂ is MgO rich, suggesting that its removal from unit Qbb₂ (sample 216L) would deplete the magma in MgO, as in analyses 215L of unit QTsf. Unit descriptions of QTsf and the image of its vent (V9336A) corroborate this choice. Additional constraints can be applied by looking at the extensive paleomagnetic data also shown in the Correlation of Map units as well as in the Paleomagnetic thematic map. Maps, images, and correlation charts can be exported and used as supportive figures in the final write-up.

OUTCOMES

We developed and administered an assessment survey at UW Milwaukee to assess the impact of the research project on student learning and student perceptions using the Student Assessment of Learning Gains (SALG) (Seymour, 1997). In the survey, students provide anonymous responses to a series of questions aimed at discovering which aspects of the course were most effective in their learning. The survey was modified from previous SALG surveys that have been successfully implemented in a variety of other science courses across the nation (examples can be found at the SALG website). The assessment survey was administered in the petrology course at UW Milwaukee pre- and post- the TSP research project. Results of the questions relevant to the TSP project are listed in Table 1. The pre-TSP survey provided a baseline to compare the learning gains made through the TSP project. The results indicate that, on average, the students made noticeable gains in their confidence of their ability to do research and to understand petrology. Their enthusiasm for petrology as a topic made the most gain. Student comments include: "Wish there were more projects like the TSP. It made me learn more." The SALG instrument is geared toward students' self-assessment of their own learning gains. Future assessments will have more detailed exploration of gains made in spatial reasoning skills and ability to integrate and synthesize large multi-component data sets.

At the University of Massachusetts, students whole-heartedly supported using "real data" for their work. For the courses at both UW Milwaukee and U Mass, the DDM projects provided the geology undergraduate majors with their first inquiry-based research experience in a classroom setting. The students learned science by doing it. Most students are more motivated to learn when they are allowed to follow their own natural curiosity in a hands-on manner (e.g. Stager, 1994; NRC, 2000). Both the semi-quantitative evaluation and antidotal evidence revealed that the students made positive learning gains in their enthusiasm for the subject and their confidence in their own ability be creative and do research.

FUTURE WORK AND EXPANDED APPLICATIONS OF DDMs

DDMs provide a creative approach to circumventing limited access to field areas because of geographical, financial and time limitations. New DDM versions of the SVF project will include many more images, video clips and two directed field trips through the volcanic field. Newer cross-platform and web-enabled versions of the DDMs are being produced under a NSF-DUE-CCLI grant to Condit; beta versions of these are currently available on the DDM web site (Condit, 2004). This will enable instructors and students to create their own DDMs based on any field area of interest. One major advantage of DDMs is that instructors could customize the projects to their own courses or research. A web-enabled version will expand the potential of the DDMs to much broader applications and fields such as geomorphology, historical geology, environmental geology, hydrology and structural geology. DDMs are versatile and can potentially be adapted effectively from introductory geology courses to research-oriented graduate level courses. An example of this is the DDM of New England, which includes six field trips and is used to pre-run the trips taken by the introductory physical geology labs (Condit, 2000; Condit, 2004). In the future we envision a broad spectrum of DDM projects that could be created and available in a web-based format on an educational site such as the Digital Library for Earth System Education (DLESE, 2004). Associated with the NSF grant will be a more in depth and rigorous evaluation of the use of DDMs and will include quantitative assessment on student learning, for example the impact on students spatial reasoning skills.

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