The Campus Mine: An Adaptable Instruction Approach Using Simulated Underground Geology in a Campus Building to Improve Geospatial Reasoning before Fieldwork

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ABSTRACT

Geospatial skills are critical to effective geologic mapping, and many geoscience students experience challenges in developing good geologic interpretation and projection skills. A physical (non-virtual) underground mine mapping simulation in a building on the Adams State College campus in Alamosa, Colorado, provides an excellent cost-effective and efficient learning tool to prepare students for actual field mapping, while improving spatial thinking using a physical hands-on setting. In this simulation students act as mine geologists, completing simulated mine mapping work tasks. Mapping and interpretive skills are enhanced in an adaptable, flexible, and easily implemented simulation that is software independent. The mine simulation is well received by students as an effective training and learning tool.

INTRODUCTION

Learning geological field skills is generally believed to be one of the most important aspects of a geoscience student's education. Unfortunately, factors such as time and expense often restrict the ability of programs to incorporate field components directly into each and every course. Many creative and effective approaches to address these factors appear in the geoscience education literature. Pilburn et al. (2002) use interactive visualization modules, in addition to other multimedia techniques. Knapp et al. (2006) tie several different exercises into a field context, and Rapp et al. (2007) were able to develop and improve student map projection skills. This article describes a relatively simple and adaptable approach to simulating field mapping by using a campus building set up to represent an underground mine (The Campus Mine).

Even if geologists perform excellent surface mapping, they must often speculate on the subsurface geology. Effective predictions of the subsurface are an acquired skill derived from experience. Geoscience students at first are often intimidated and overwhelmed by all but the simplest subsurface predictions, typically geological cross-sections. More complex predictions of subsurface geochemical behavior, structural relationships, solid body modeling, and so forth can be even more difficult. Taylor et al. (2004) describe some of the cognitive hurdles students face in complex visual displays and provide effective strategies for understanding topographic maps.

Modern geoscience students have access to increasingly sophisticated technology and three-dimensional (3D) modeling software packages. Nonetheless, there is an important and critical link to be made between the virtual world and the physical real world of the outcrop and the field setting. Furthermore, many teaching simulations and methods are often limited by significant time and preparation requirements. The underground mine mapping simulation described here provides a highly adaptable, physical, non-virtual venue for introducing students to a wide variety of these modeling techniques, while still preserving the tangible hands-on experience of nearly all aspects of actual field mapping.

The purpose of the underground mine mapping simulation is to help develop mapping skills and the associated three-dimensional perception required for effective geological interpretation. Underground mines often provide an excellent look at actual rock exposures in three dimensions. For example, underground mining operations may expose a series of faults, intrusions, and/or veins within a complex sedimentary sequence on one particular physical mine level. After completing mapping on that level, a mine geologist will typically project the intersected geology into areas of potential or possible future mining at different levels, revising and re-interpreting the geology between levels as more exposure is produced with additional mining activity. The herein-described underground mine mapping simulation allows the same opportunity for students, where different levels can be introduced or staged for students to map over a period of time.

The Adams State College class using the underground mine mapping simulation is a biannual senior-level, spring-semester field methods course (GEOL 446, *Field Methods*) that prepares students for a 6-credit capstone field geology course conducted entirely in the field. Minimum course prerequisites for *Field Methods* include structural geology and at least one field-based class, with petrology and other courses strongly recommended. GEOL 446, *Field Methods* is a required course in the BS Geology degree track, one of four geoscience degree tracks offered by the Earth Sciences program within the Department of Biology and Earth Sciences at Adams State College. The degree requirements can be viewed at http://www.adams.edu/academics/earthscience/degree/degree.php. The program has 45 to 55 majors served by two full-time faculty members and one part-time faculty member. The small department size allows a significant level of insight into student progress over a several-year period. Adams State College is located in south-central Colorado in the heart of the Rio Grande rift in Alamosa, Colorado, with a residential campus population of about 2500 students. Adams State College is also a designated Hispanic Serving Institution (HSI), although GEOL 446 historically has not had a high percentage of Hispanic students. In the most recent course offering, the class size was small with only 10 students, but class diversity was well balanced with regard to gender, college experience, and age. The class was 56%

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female, 67% traditional, and 33% transfer, with student ages ranging from about 20 to 55 years. Traditional students at Adams State College are defined as those less than 24 years of age or out of high school for less than 5 years. Transfer students are those who have completed coursework at institutions other than Adams State College.

Since 2001, *Field Methods* has used the underground mine mapping simulation with several different geology layouts. A standard textbook (Bevier, 2006) is used to provide basic introductions and effective exercises for geological field mapping concepts. The underground mapping simulation provides an exceptional application that addresses required geoscience skills. Excellent virtual exercises are available and can be used to complement the techniques described here, e.g., Pilburn et al. (2002).

METHOD

The Campus Mine Simulation

Traditional, but by no means dated, field mapping techniques require effective data collection, organization, and interpretation. Underground mine operations or workings provide a unique opportunity to collect data in a small area on large-scale maps. Furthermore, multiple levels of underground workings, when mapped, provide an excellent opportunity for a wide variety of spatial analysis applications. But access to underground workings is seldom available for undergraduate coursework, especially in an operating mine where safety training, liability and other considerations must be taken into account. One notable exception to this lack of access is the Edgar Mine, operated for degree programs offered by the Colorado School of Mines.

The underground mine simulation at Adams State College is set up in Porter Hall, a three-story building on campus (Figures 1, 2, and 3). The hallways and connecting stairwells provide an excellent physical layout of "adits, crosscuts, and shafts." These physical workings are mapped by students using basic Brunton and survey-tape techniques (Compton, 1985; Bevier, 2006) to generate a series of to-scale base maps of each level with corresponding cross sections. These can be compared to a mine "key" or master map. An example of a simplified master map is included to illustrate a basic tilted and faulted sedimentary sequence (Figure 2). Geological information is posted on the hallway walls using outcrop cards (Figure 4). The outcrop cards describe the geology at that location and range from simple position information to more detailed descriptions of structures, lithologies, or other information that might be collected from a mine wall. A more detailed outcrop card might include contact orientations and character, lithology relationships, small scale structural features, etc. Permanent geological information is not used, meaning that all information is easily removed at the conclusion of class. This feature not only allows the simulated geology of the mine to be customized but allows the mine scenario to be changed with every class.

An important role-playing part of the simulation casts the students as mine geologists. Students receive memos from the Chief Mine Geologist (the class professor) describing the work needs or class assignment for the

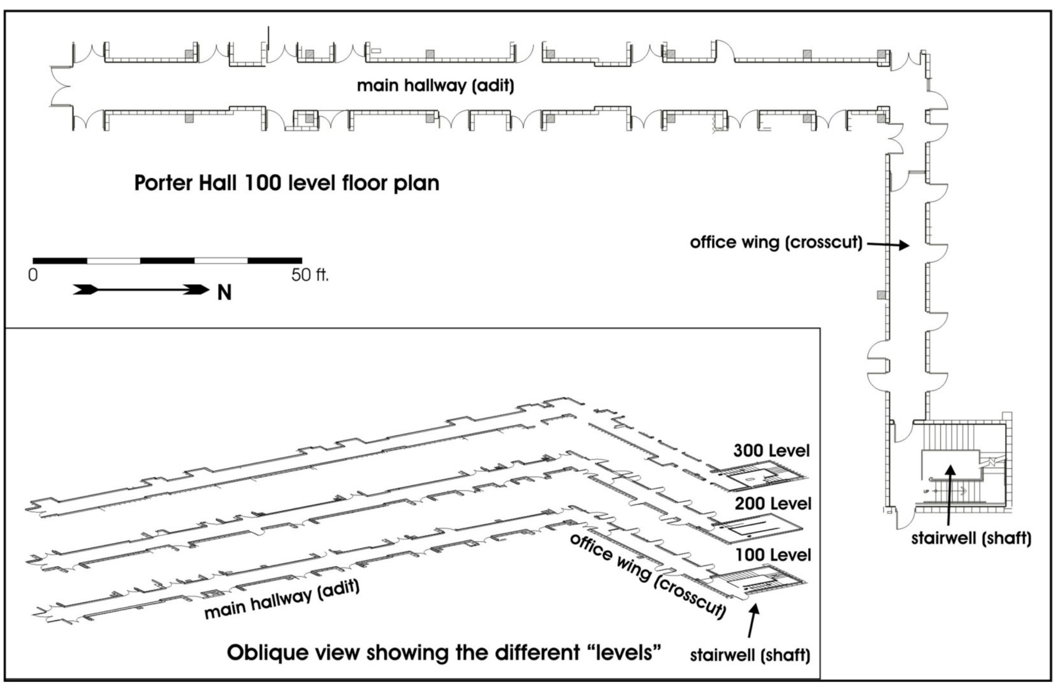

FIGURE 1. Simplified engineering drawing of the first floor of Porter Hall, showing the main hallway (adit), the office wing (crosscut) and stairwell (shaft) connecting to upper levels. The second and third floors of Porter Hall are similar in design. The main hallway is 150 ft. long, the office wing is 64 ft. long, and the stairwell is 20 ft. by 16 ft. The inset shows an oblique view of the three levels (1st, 2nd, and 3rd floors) of Porter Hall, drawn using Google Sketchup. View is to the northwest, floors are 14 ft. apart.

"mine work shift." The "mine work shift" is generally 7 days, although "production schedules" are sometimes changed or "safety issues" suddenly preclude access. The intent of these changes is to both simulate actual mine conditions and reduce the effect of procrastination. Students get information via these memos on mine "conditions," i.e., when mine workings are accessible (new information is now posted in the hall), when faunal samples are back from the paleo prep lab (new fossils corresponding to lithologies are laid out in the lab to be examined), the geochemical results are back from the assay lab (data is now available for some samples), or when a union strike or safety inspection has closed off all or part of the workings (information is no longer posted on the hallway walls). Examples of these memos are shown in Figure 5. A final report describing the structure, lithologies, history, and other general geology is submitted at the conclusion of the mine mapping. A final "staff meeting" is held with the Chief Mine Geologist to discuss various interpretations and ore projections. The entire mine mapping exercise typically takes 3 to 4 weeks to complete.

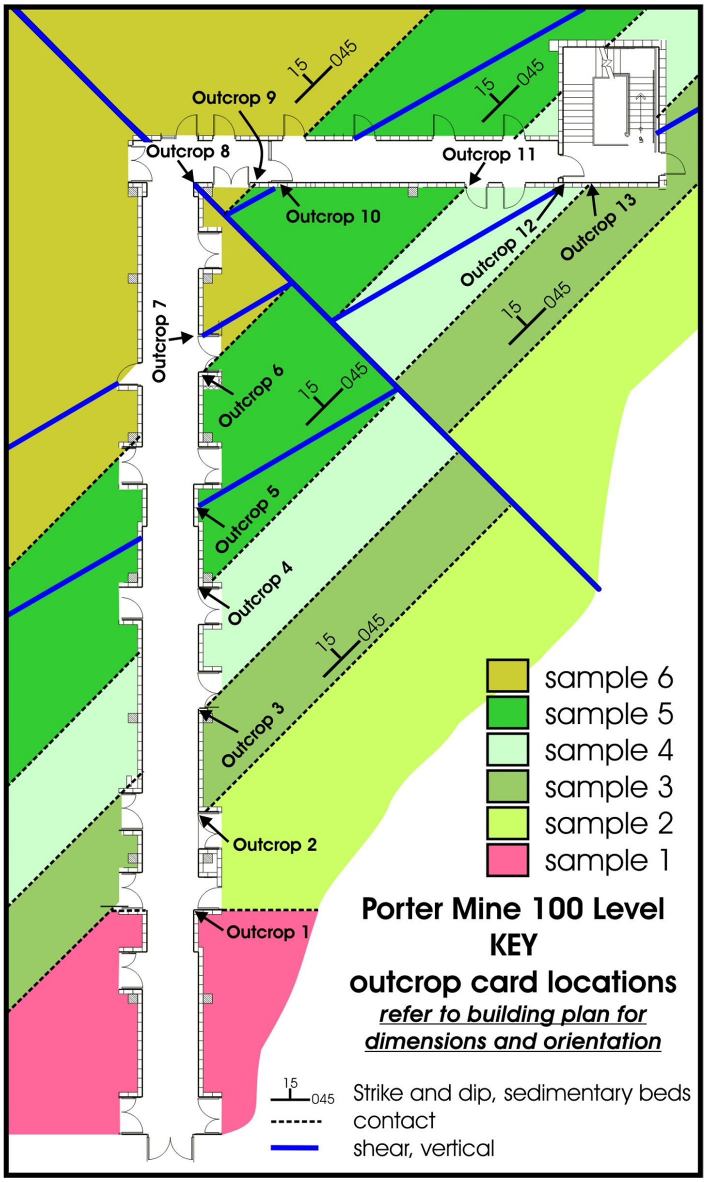

FIGURE 2. Example of a simplified mine map key, 100 Level, with locations of outcrop cards shown in call-outs. The corresponding outcrop cards are shown in Figure 4. The sample key refers to representative rock samples that are available for description in a laboratory room. Sample 1 is a granitic rock, and samples 2 through 6 are sedimentary rocks. Note that any other materials related to the sample, such as thin sections, etc., would also be in the laboratory room. Refer to FIGURE 1 for hallway dimensions.

After students complete a base-map of the mine workings or layout, the geology information is posted using the previously-described outcrop cards. Obviously a complete view of an outcrop cannot be simulated. Sample numbers are placed on outcrop cards that are attached to the "mine" or hallway walls (Figure 4). Each card refers to a rock sample that is available for description in the laboratory. Structural information is indicated in a similar fashion. Contacts and faults are described on similar cards containing contact orientation information and corresponding lithologic relationships. Students plot locations and information on the base maps they generated in the first step of the simulation. The students then infer and project contacts, faults, and other mapped data into areas that are not "exposed." Depending on the class interest or focus, whole-rock analyses or other geochemical information, rock ages, faunal data, etc. can be provided after the initial mapping is completed, simulating the lag time associated with laboratory work. The same is true for any petrography, where matching thin sections are placed out for description after the initial map work is done. Students project the geology between the three floors of the building and produce a report with maps, cross sections and geologic history. An example of a projected fault is shown in Figure 3.

Projecting the geology between floors is where most students encounter pitfalls. Virtually all students can visualize where vertical faults or other planar structures will intersect the overlying floors, but inclined projection intersections are less obvious. In general, students sometimes have difficulty accepting that their initial projections are indeed correct, leading to second-guessing and incorrect changes. This second-guessing may be due to lack of confidence and/or the inability to see the entire projected feature in one view. With surface outcrops it is sometimes possible to find another vantage point to confirm a geologic projection, but this is rarely possible in an underground setting. Instructor intervention in this case generally involves walking students through the halls/workings, double-checking their measurements and data plots, and discussing the projection. Readjusting to different map scales is sometimes a problem. Many students have prior experience with 1:24,000 scale topographic maps and discover that it takes a little bit of effort to get used to much larger map scales of 1:120 or 1:240. However, none of these problems are insurmountable, especially with a walk through the "mine."

Using a simple floor plan, it is possible to rapidly create a wide variety of geological scenarios to challenge

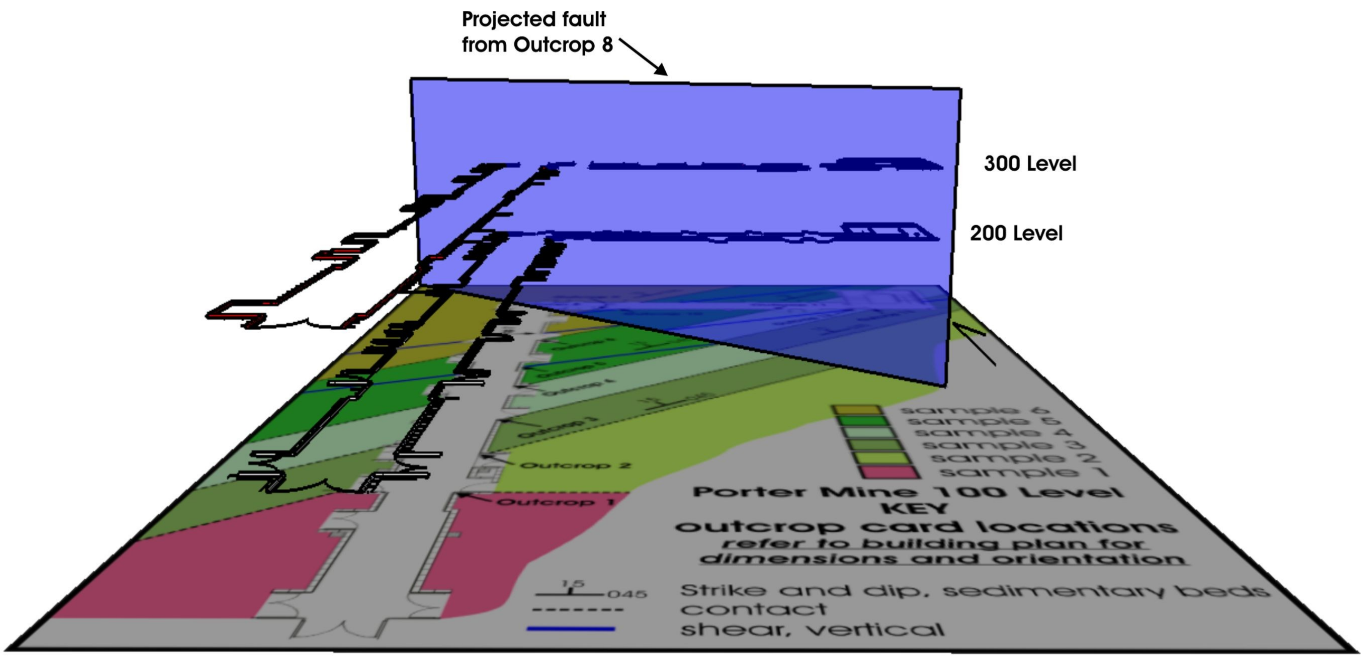

FIGURE 3. Oblique view looking to the north showing the information from Outcrop 8 projected upward through the 200 and 300 Levels of the Porter Mine simulation. The 100 Level map from Figure 2 is shown here. This is a simple type of projection that students make to infer the geology between levels.

students and develop spatial analysis skills. When this simulation was initially conceived, a basic single floor plan was used, with a simple tilted and faulted sedimentary rock sequence superimposed on the floor plan. The intersections of the faults and contacts with hallway walls on all levels were labeled with cards. In later iterations, the geology was projected up to the second and third floors.

Generally, it is quite easy to accurately locate card positions by referring to doorways, windows and so on. The most recent mine mapping simulation used at Adams State College included faunal samples for biostratigraphic information critical to developing a correct geological history (and finding the thrust fault). Building maps are often available from the campus facilities offices. Developing a good mine mapping layout for the physical simulation is not software specific. The geology can be developed in several ways, using paper maps, CAD programs, or one of many other graphics programs. Google Sketchup is an excellent free software package for creating general 3D models that allow real-time view rotation for demonstration purposes, but Google Sketchup seems to be more cumbersome for detailed geology. The mine simulation has the potential to be adapted to geographic information system (GIS) software, providing an excellent opportunity for students to gain experience with data collection and interpretation using GIS techniques. Mastery of these field and office GIS technologies will make actual field mapping time more useful and efficient and will further GIS spatial-thinking goals suggested by Downs (2006).

Possible problems for the instructor in designing and implementing the Campus Mine fall into three general

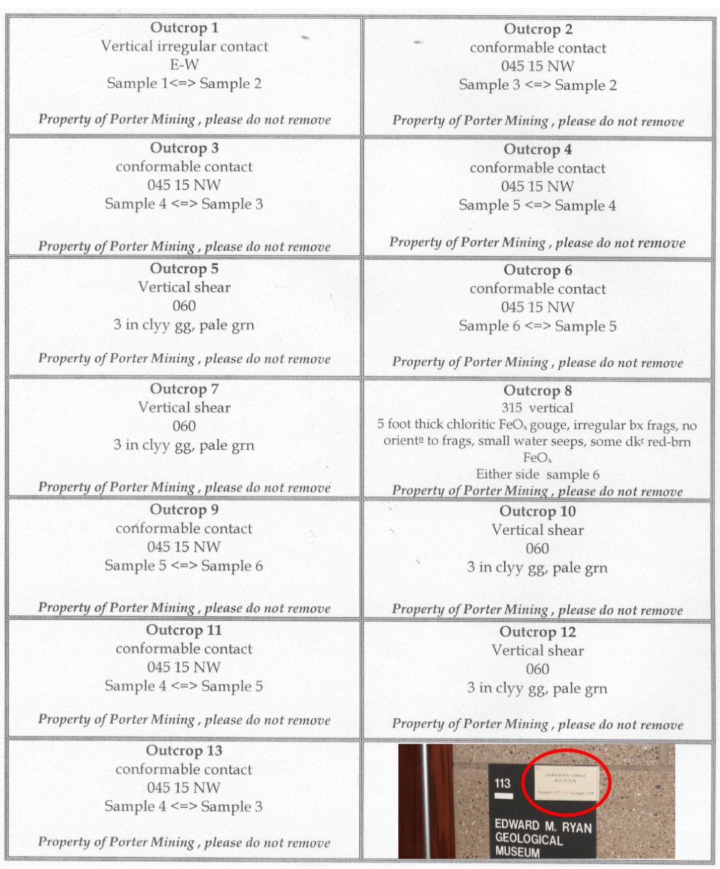

FIGURE 4. Examples of an outcrop card sheet. Sheets are printed on card stock and cut into individual outcrop cards for placement. See FIGURE 2 for location information of this example sheet. For mapping purposes, the contact or structure referred to on the card passes through the "=" sign on the card. This convention works well but could easily be changed. The lower right photograph shows a card taped to an easily referenced location in Porter Hall. The Room 113 sign is 6 inches wide.

FROM: RG BENSON
TO: ALL STAFF GEOLOGISTS
RE: PORTER MINE MAPPING
DATE: 30 MAR 09

Outcrops and underground mapping requirements for each group

1. There are 19 new outcrops on the 100 level. These represent the only exposures so far in this dirty, dusty underground operation. They will be mined out by 0530 on 1 APR 09 at the end of night shift.
2. The 200 and 300 levels will be accessible early next week, but may also be mined out on short notice. Two years ago, there was a UMW strike and the mining work did not advance as quickly. Production demands compressed the mapping schedule considerably.
3. Additional geochemical and faunal information may also be available early next week. During the regular scheduled safety meeting, I will be available for any questions.
4. Plot all of the contacts your map. The contact position lies between the arrows, with each arrow pointing to the side of the contact that the lithology is on. Assume all outcrop positions are at waist height.
5. Interpret the geology completely and infer the all geology present, including the right crosscut and the connecting shaft. Be sure to project the geology between the crosscut and the adit, as management is looking for new targets in that area.
6. Prepare a high quality maps and "bent" cross sections for each level, using your mapping base from earlier work.
7. Prepare a brief geologic history of the area, based on what you've done. You may wish to complete the strat column section first, before doing this step. More reporting requirements will follow, so please consider all work in draft/revisionist status.

A preliminary review is due on 14 APR 09. A complete group report is due at 1300 on 28 APR 09, not before. Be prepared for discussion, and to show your work to everyone, especially me!

Work in your group, but collaboration is encouraged.

RGB

FROM: RG BENSON
TO: ALL STAFF GEOLOGISTS
RE: PORTER MINE MAPPING
DATE: 6 APR 09

Additional information arrived over the weekend. Unfortunately, the annual two-week shutdown started before the new advances could be washed clean. The Safety Superintendent cleared the area for work on the 200 and 300 levels. I toured the levels this morning and outcrops are minimal. I suggest that you complete mapping on those levels ASAP.

New info is as follows:

1. Some biostrat samples were cleaned up and returned to my office today. Please examine them as soon as possible.
   a. Sample ASC1409 is from the formation represented by 161
   b. Sample 1219 is from the formation represented by 148
   c. Sample ZuLu is from the formation represented by 143
2. Geochem results were emailed this morning, as follows:

Analytical results are from Wahoo Labs.

Sample No.		122	8
All values in %			
SiO_2		76.35	68.05
TiO_2		0.11	0.43
Al_2O_3		13.13	16.73
$FeTO_3$		0.76	2.93
MgO		0.15	0.46
CaO		0.69	2.26
Na_2O		4.11	4.39
K_2O		4.81	3.99
P_2O_5		0.02	0.19
MnO		0.14	0.07
LOI		0.20	1.26
Total		100.27	99.50

3. The "Prospector": some gnarly, smelly individual came by my office yesterday with an alleged ore sample reeking of nicotine. He claims it came from an area just above the mine. Please give me your opinions on this sample and where it might fit in the geologic picture. I want pros and cons. You will see the sample in with the others. I had to drench it in acetone to get the smell off.

Don't forget all of the reporting requirements. See me if questions, and see you at the safety meeting tomorrow.

RGB

FIGURE 5. Examples of memo to mine staff (GEOL 446 students) outlining work needs. This memo describes new information available, as well as status on the upper levels/floors.

categories. First, locating good, as-built construction plans that actually match the building housing the mine simulation can sometimes be a challenge, especially in older buildings. Here the value of CAD drawings cannot be underestimated. In this first view of the building plan where the mine exercise is to be situated, the complexity of the initial base map or maps should be considered carefully. Sharp bends in hallways are fairly easy for students to map, as are stairwells as "mine shafts," but long gently-curved hallways may introduce a level of surveying complexity that field geologists are not likely to use often, if at all. Other considerations include what map scale to use, where the geology is mapped (i.e., floor height, ceiling height), etc. Second, mine "maintenance" can be an important consideration. The outcrop cards may vanish during the course of the operation/exercise. The geology of the mine must be carefully designed to take advantage of easily-located features for replacing outcrop cards that may be lost due to a variety of causes. This is a situation where the extra detail of the as-built plans referred to above can really help. While a long expanse of bare wall might seem like a tempting canvas to lay out a detailed array of underground geologic features, it might be very time-consuming to re-establish in the event of vandalism or misguided cleanup. Third, do not assume compasses will work in a building, other than to measure dip or other angles. As a general caution, overly complex geology should not be attempted in the first implementation.

Student feedback

In past *Field Methods* courses, student feedback about the underground mine simulation was directly solicited with a simple survey. The questions were:

1. What were the biggest challenges you encountered in completing the exercise?
2. What was your biggest knowledge, asset or skill that helped you complete the exercise?
3. What did you find to be the best part of the exercise?
4. Conversely, what did you find to be the worst part?

Not all students responded in a timely fashion to the survey, requiring some direct interviewing, but the following verbatim responses summarize student reactions about the exercise quite well:

- "The challenge was performing spatially at that scale relating between floors and off the side halls. And knowing it was small compared to a mine, but the reality of marching all over a large horizontal area, and vertical layers, instead of just doing a book exercise made it feel like you were learning something REALworld, not just theory."
- "The knowledge of being able to even read the tags and interpret their notes made me feel like I was starting to get in on the Big Secret of understanding geology. It was learning how to approach the puzzle."
- "The surprise best part was the teamwork of discussing findings and adjusting your notes, or the others considering your findings to be more correct and adjusting their info. It was a good feeling of a team effort gathering data, less missed information."
- "The worst part was logging accurate notes in the field book that I could read and understand later. A skill to be developed."
- "Great exercise, Dr B! It made a big impression, we were terrified of the hugeness of it."

Examples of work from several students and an instructor key for comparison are shown in Figure 6. As demonstrated by these examples, students were able to effectively interpret and project geology throughout the mine area. Furthermore, different interpretive scenarios of the geology were made, and students were able to discuss and argue with each other the merits of these different scenarios. Figure 6 illustrates slightly different student interpretations of cross-cutting relationships and fault projections. Three examples correctly identified a thrust fault based on biostratigraphic faunal information provided after initial mapping was completed. This additional information is described in the mine memos in Figure 5. Figure 7 also illustrates some of the problems that students might have with the mapping, including incorrect orientations and projections.

Students appreciate the hands-on feel of the underground mine simulation, along with the professional geologist role in which they are cast. They also appreciate the staged release of information, which emphasizes the components of mapping without overwhelming the student. While students do not actually wear hard hats or insist that mapping be done in the dark with headlamps, they do enjoy the memos outlining the expectations, as if they are really employed as mine geologists. All student comments indicate that the mine simulation is a unique approach to improving 3D thinking skills. They remark that the lack of visual clues normally found on an outcrop prevents their making too many assumptions and foregone conclusions, no surprise since the paucity of information forces students to rely on small bits of controlled information placed in a correct spatial setting. The wealth of additional observations from an actual outcrop or mine working is not available to them. But this simplification makes students map carefully, and more importantly, forces them to consider the 3D context thoroughly. For example, a fault plane in an outcrop often

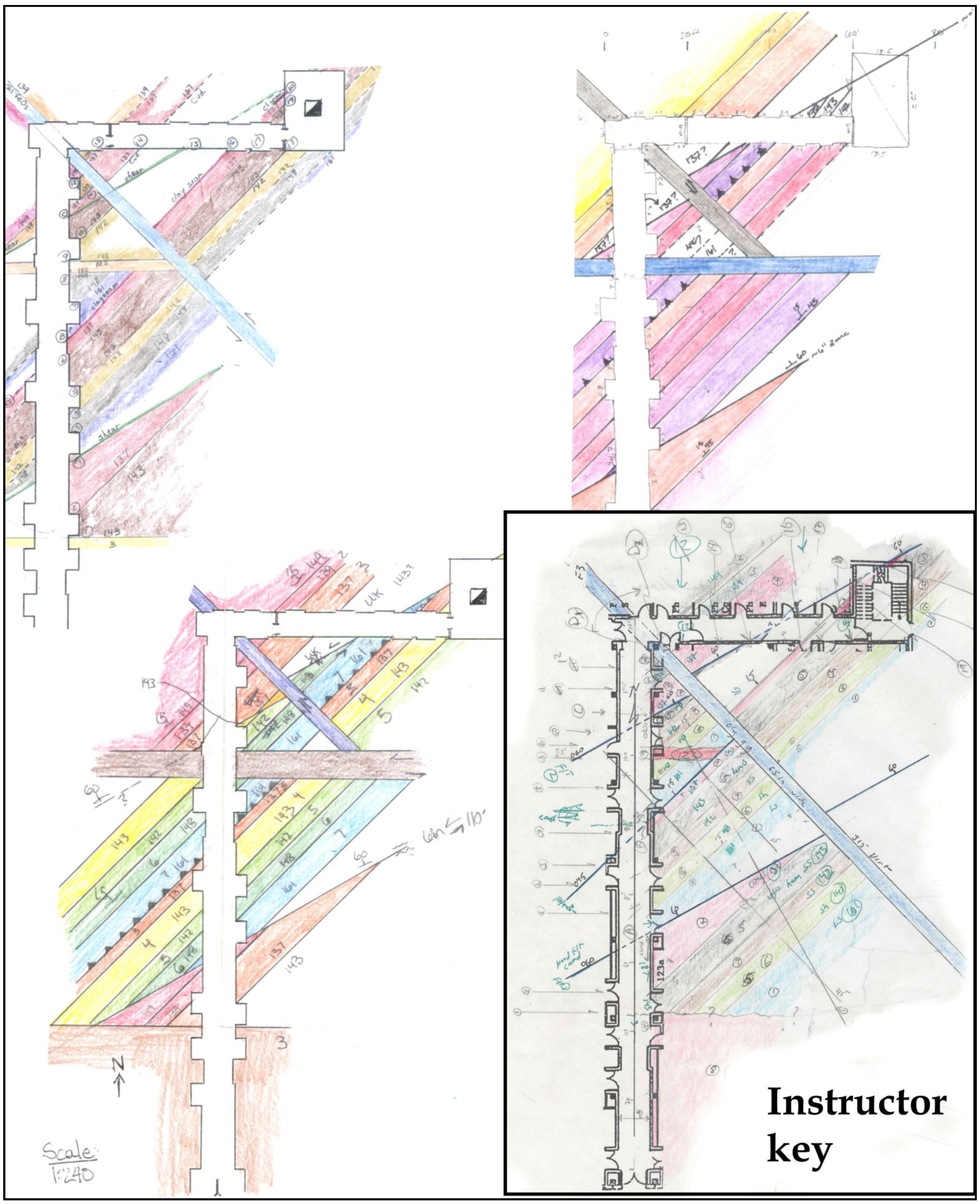

FIGURE 6. Examples of student work shown here were mapped from a more complex geologic scenario than the one shown in Figure 2. The instructor key is shown for comparison. The student maps and the instructor key are field sheets and illustrate different interpretations of outcrop card information posted on the 100 level or first floor. Fault cross-cutting relationships are the most obvious interpretive difference among these three maps.

provides a good visual 3D orientation clue, but when the same orientation is simply a map point and symbol with no visible orientation hint, a student cannot avoid spatial reasoning to infer the projection of the fault.

Though this paper reports on the use of a simple student feedback survey for the Campus Mine simulation, spatial learning and reasoning improvements over the duration of the course are not addressed. Such knowledge will be important to study in the future, as new geoscience discoveries are made and concepts evolve. An effective assessment instrument for the Campus Mine simulation should determine how well students improve spatial thinking and reasoning skills as a result of completing the course.

Assessment of geoscience field skills is not a new idea. McKinstry (1948) and Compton (1985) both emphasize that mastery of spatial skills is critical to successful geologic practice. Perkins (2004) suggests that assessment

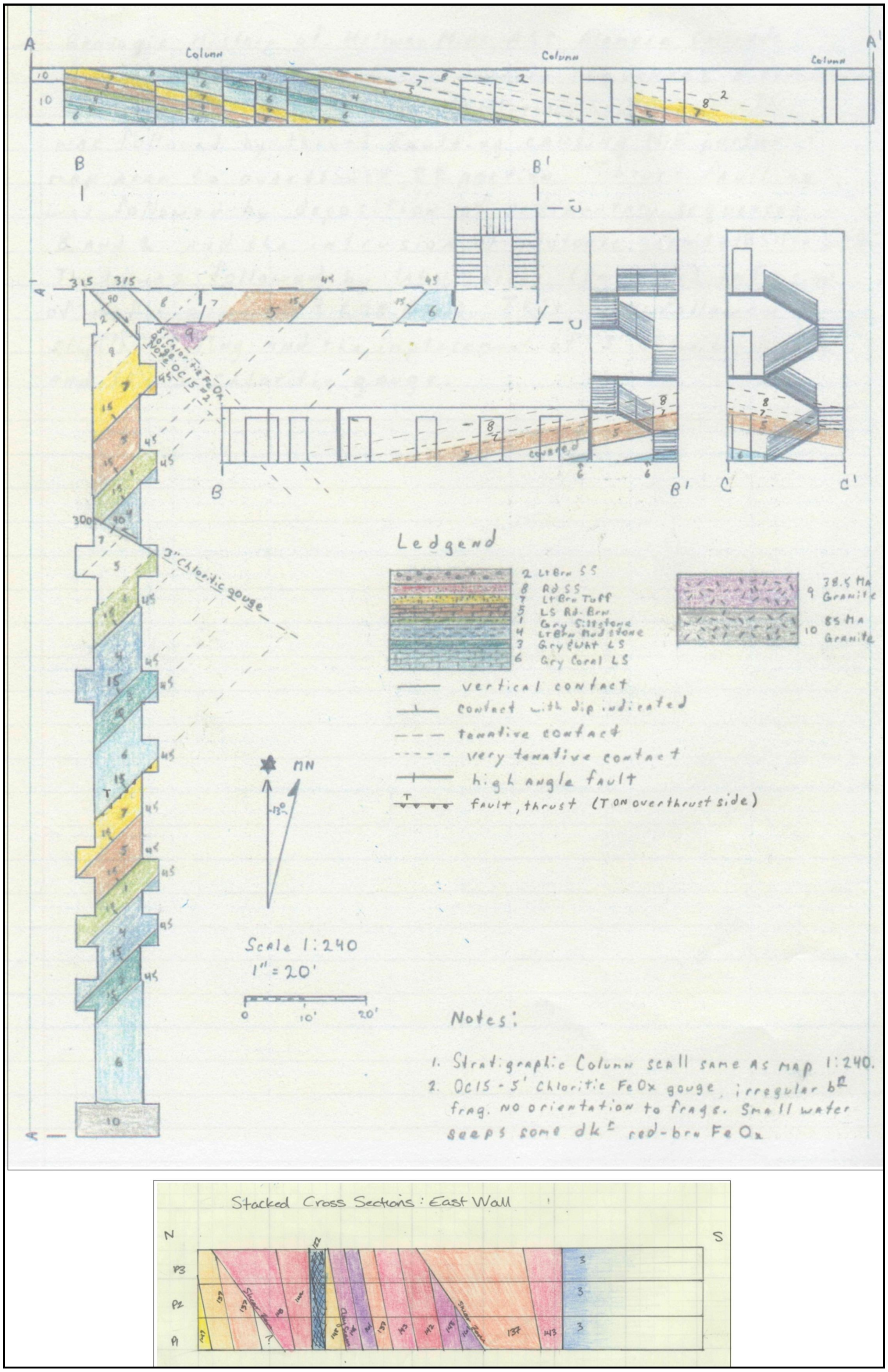

FIGURE 7. Student work examples shown here illustrate some of the simulation pitfalls. The larger upper map and cross-section group demonstrate superb attention to detail but show little geologic projection. The smaller stacked cross section shows geology projected from all three levels, but has incorrect interpretation of many orientations of the sedimentary units. This map and associated cross sections represent parts of final reports.

of spatial learning and reasoning in earth science classes is problematic, yet necessary.

Many effective assessment techniques are available (Angelo and Cross, 1993; Cross and Steadman, 1996; Anderson et al., 2001; Gosselin and Macklem-Hurst, 2002; Kastens et al., 2008; Kastens and Rivet, 2008), as well as methods for assessing student spatial perception problems (Bodnar and Guay, 1997; Kali and Orion, 1996; Kastens and Ishikawa, 2008). The Geoscience Content Inventory described by Libarkin and Anderson (2005) may provide a better overall assessment of the Campus Mine simulation.

DISCUSSION

The underground mine mapping simulation can be modified to accommodate many geoscience specialty areas. For example, a complex folding pattern could be developed and superimposed on a building plan, allowing mapping and use of stereonets to derive a deformation history. Sedimentary environments with associated faunal sequences could be superimposed on the mine geology to provide a biostratigraphic dimension. Other possibilities include assigning thin sections and chemical analyses to different locations in the mine as part of a petrology class exercise. Any economic geology applications with ore reserve calculations, hydrothermal alteration, etc., can be used. Even if the mine geology consists of a single igneous rock type, students will be able to place the analytical work into a spatial context and produce a realistic interpretation. If field computers/data recorders are used in the Campus Mine, students will also have an opportunity to master more sophisticated GIS mapping technologies before leaving for the field. If students have technical problems and require assistance, the instructor is usually more accessible in the Campus Mine than when in the field. Having students work with unfamiliar technology before going in the field will mitigate later problems in a field setting. In the Adams State College setting, using a larger building than Porter Hall, or perhaps expanding the Campus Mine to two buildings might offer more geology components. If a campus has any real outcrops of sedimentary rock, cross-cutting intrusions, etc., this actual geology might be built into the mine geological setting to provide another level of projection.

The possibilities for using this mine mapping simulation in a variety of campus settings and applications are many. The hands-on philosophy of the exercise can be complemented with imaginative cross-curricular collaborations, with engineering programs, environmental planning studies, and so on. Projects developing cross-curricular applications are beyond the scope of this article, but such applications may work well in many situations. If sophisticated modeling software is available, digitizing the Campus Mine may provide additional possibilities for interpretation and discussion.

CONCLUSION

The Campus Mine simulation is effectively and efficiently useable in a wide range of applications, is adaptable to many software programs, and is very cost effective. The mapping opportunities provided by a simulated underground mine and associated geology provide a highly adaptable method for training students in spatial thinking and reasoning by simulating real-world geologic scenarios in a campus setting. Students enjoy working with the simulation and are able to develop useful field skills. They are able to evaluate different interpretations from the same geologic dataset. The ease of design and the adaptability to a variety of geological scenarios and software is a significant incentive to using the simulation.

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