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The Effectiveness of Petrified Wood as a Geobiological Portal to Increase Public Understanding of Geologic Time, Fossilization, and Evolution

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1. Introduction

Petrified wood is ubiquitous, and is found in every US state and on every continent. Because of its abundance and intriguing nature, we hypothesized that fossilized wood might be an effective gateway through which important interdisciplinary scientific concepts could be taught. Our earliest investigations of *in situ* petrified wood at informal education sites revealed that petrified wood could spark public interest about its formation, and its seemingly paradoxical nature. Upon this original viewer interest, scientific content in chemical composition, fossilization processes, extinction events, evolutionary processes, and geologic time could then be scaffolded, in either informal or formal educational settings. In our first classroom investigations, we probed the effectiveness of petrified wood as a portal in college Earth History courses to address geologic age, fossilization processes, and fossil properties (Clary & Wandersee, 2007). Through classroom incorporation of petrified wood, instructors identified students' alternative conceptions, and significant student gains in some scientific content were evident at the end of the semester. In a subsequent research investigation, students in a junior level Landscape Architecture design class were assigned a project in which they developed an informal educational space that conceptualized geologic time (Clary, Brzuszek, & Wandersee, 2009). Petrified wood was used to measure student gains in the understanding of geologic time, and data revealed that a threshold petrified wood conceptual knowledge was present in all successful design solutions. Through our research, we identified petrified wood as a potential geobiological portal to address public understanding of geologic time, identified by Stephen Jay Gould (1987) as one of the major scientific constructs of all time, paralleling evolutionary theory in its importance.
Our latest petrified wood research focuses upon an earlier educational influence in our future citizens' geological literacy. In this current study, we investigate primary and secondary teachers' geobiological content knowledge of petrified wood, and probe potential investigative techniques for effective petrified wood study within K-12 classrooms. We also attempt to ascertain the role of science professional development programs for increasing teacher content knowledge in geologic time and fossilization processes.

2. Theoretical background

One goal of the EarthScholars Research Group™ is to improve public understanding of science through novel, integrated learning approaches. With researchers' scientific backgrounds in geology and biology (botany), we are inspired to identify, emphasize and promote the intersections between our two disciplines for an integrated, geobiological understanding of science. We research science education opportunities at informal science sites, as well as the potential for the improved articulation of integrated science instruction in formal science classrooms. Our research is guided by the learning theory of human constructivism, and we strive to promote meaningful learning in science classrooms by introducing new concepts that connect in substantive ways to our learners' prior knowledge. We also strive to provide context to scientific concepts and constructs in order to accurately depict the nature of science to our students, in contrast to the "final form science" (Duschl, 1990) that exists in many modern classrooms. Because our research agenda promotes integrated geobiological education, we ascribe to the Big Ideas in Earth Science as identified by the Earth Science Literacy Initiative (2010). These Big Ideas are interdisciplinary in content, and promote an authentic view of science.

2.1 Nature of science, integration of scientific concepts, and the history of science in science instruction

To promote a valid view of science, traditional classroom and informal science instruction must move beyond a collected set of seemingly unrelated facts, concepts, and theories. Without the context for how the scientific knowledge emerged and developed, students may leave the classroom with only the "rhetoric of conclusions" (Schwab, 1962), and fail to connect the content knowledge between one science course and the next. The non-contextual accumulation of knowledge is also present outside the classroom: Suzuki (2004) noted that world events are presented without context, leading to confusion and frustration in the general population. Integrated, interconnected science can help facilitate student understanding of our planet's complexity (Orr, 1994).

The context in which scientific concepts and theories developed also has value for the science classroom. The history of science can help students view science as an interesting practice, as it reveals the social, political, and cultural influences from which the constructs and theories emerged (Matthews, 1994). The nature of science is revealed when students understand how scientific knowledge is restructured as new data are collected and new research investigations modify previous conclusions (Duschl, 1994). Although some conclusions are later exposed as erroneous, the inclusion of this history is intellectually honest for our students, and reveals how scientific methodology ultimately overturns poor research studies and corrects false conclusions (Clary, Wandersee, & Carpinelli, 2008). The history and philosophy of science not only provides context, but can also humanize a science curriculum (Jenkins, 1989).

2.2 Learning theory of human constructivism

The learning theory guiding EarthScholars Research Group™ is that of human constructivism, as developed by Novak (1977) and elaborated by Mintzes, Wandersee, and Novak (1998, 2000). Human constructivism builds upon the work of cognitive psychologist David Ausubel (1963, 1968; Ausubul, Novak, & Hanesian, 1978) and Novak's (1963) fundamental principles for science education research. Theoretical principles arising from human constructivism posit that humans are meaning-makers, and that learning occurs when there is a change in the meaning of experience. Meaningful learning occurs when learners can connect new concepts to their existing knowledge frameworks in new, non-verbatim ways, leading to either strong or weak cognitive restructuring. Therefore, the goal of science education is to foster conceptual change in learners that can lead to more powerful knowledge structures and an understanding of our planet.

Science instruction that leads to meaningful learning will promote quality over quantity of material, meaning of concepts over memorization, and an understanding of scientific concepts and constructs over simple awareness (Mintzes et al., 1998). Therefore, a selected set of concepts should be taught in a meaningful way, as opposed to brief overview of a large number of seemingly unrelated constructs. This reduction of material presents one of the major dilemmas for Earth Science education (Bybee & Pratt, 1996). However, the core constructs of the geosciences can be identified as plate tectonics and geologic time, which also influence important constructs in other disciplines, including evolutionary theory in biology (Dodick & Orion, 2003). Because meaningful learning occurs when learners connect new concepts to their existing knowledge frameworks, teachers should assess students' prior knowledge before instruction begins, and then proceed accordingly (Ausubel et al., 1978; Mintzes et al., 1998). Some students harbor alternative or non-scientific conceptions about how science operates within the natural world (Novak & Musonda, 1991; Wandersee, Mintzes, & Novak, 1994). If these alternative conceptions (often called misconceptions in the science education literature) are not identified and addressed, science instruction can be ineffective.

2.3 Geoliteracy and the Big Ideas in Earth Science education

There is an undeniable need for the public to know and understand the planet on which we live (Clary & Wandersee, 2009). Pursuant to this understanding and compiled in congruence with the learning theory of human constructivism, the Earth Science Literacy Initiative (funded by the US National Science Foundation) identified and published the nine Big Ideas needed by the general population for geological literacy (2010). These nine big concepts are interdisciplinary in nature, and are aligned with the US National Science Education Standards (National Research Council, 1995).

The Big Ideas include the nature of repeatable and replicable scientific methodologies (Big Idea 1); geologic time (Big Idea 2); Earth System Science, in which complex and interacting "spheres" of the planet interact and influence each other (Big Idea 3); the dynamic nature of the planet (Big Idea 4); the unique role of water on our planet (Big Idea 5); the evolution of life forms and their influences on the planet (Big Idea 6); the dependence of humans on Earth's natural resources (Big Idea 7); the planet's natural hazards for humans (Big Idea 8); and the significant influence of humans on our planet (Big Idea 9). Although these Big Ideas represent the core concepts for Earth Science literacy, each concept also has connections and interactions with the other concepts.

For example, geologic time, or the 4.6 billion year history of our planet, provides the needed reference scale for tectonic evolution of the Earth, and the origin, evolution, and extinction of its life forms. Often referred to as "deep time" (Carlyle, 1832, McPhee, 1981, Rudwick, 1992), geologic time can inform us of the principles that determined our planet's history, and can help us to uncover the past trends and patterns that may help us to effectively predict Earth's future (Soreghan, 2005). An understanding of geologic time is crucial for the general geological knowledge needed by all citizens to make informed decisions about our planet (Clary & Wandersee, 2009). Notably, petrified wood study can address many of these Big Ideas, including scientific methodology (1), geologic time (2), Earth System Science (3), our changing planet (4), hydrologic influences on fossilization (5), evolution of life forms (6), and climatic changes over time, extending into the present time (9).

3. EarthScholars Research Group: Previous petrified wood investigations

The EarthScholars Research Group™ began its investigation into the role of petrified wood in science education in 2003. Because of fossil wood abundance, numerous locations exist where petrified wood is publicly displayed. While the biggest public display of petrified wood in the United States is at the Petrified Forest National Park in Arizona, other smaller sites across the US display petrified wood *in situ* as well. We visited and investigated two informal sites: the Mississippi Petrified Forest in Flora, Mississippi (Fig. 1) and the Petrified Forest, in Calistoga, California (Fig. 2). We observed and interviewed visitors and staff, analyzed each site for its effectiveness, and determined the potential of petrified wood in science learning.

We identified several opportunities to learn important scientific constructs in these informal learning environments, but noted that geologic time was not emphasized or was avoided on the self-guided trails. Likewise, scientific explanations of the formation of petrified wood were missing, partial, or incorrect. However, opportunities existed to help the public visualize how the current location differed from the past paleoenvironment in which the fossilized trees originally lived, and how scientists arrived at the ages for the fossilized wood specimens preserved at each site. A context of the displayed fossilized trees within a larger context of plant evolution would have been informative and helpful.

Fig. 1. The Mississippi Petrified Forest in Flora, MS has the largest public display of petrified wood east of the Mississippi River in the US. Signage is minimal at the site, but visitors are provided a brochure, which offers descriptions of the numbered waypoints. The fossilized wood on display is Oligocene in age (30 million years old).

The fact that both forests have drawn the public since 1871 (California) and 1854 (Mississippi) provides convincing documentation of the value of petrified wood and petrified forests for teaching geobiological literacy. Our investigation into the visitors' comments (Fig. 3) revealed that although visitors were awed by the display of the fossilized trees, several visitors invoked non-scientific views to explain their formation and presence at the site.

Fig. 2. The Petrified Forest in Calistoga, CA is noted for the druzy quartz crystals within the fossilized wood specimens. Brochures are used in lieu of signage at this site. A tourist site since 1871, the Petrified Forest displays fossilized wood from the Pliocene, approximately 3 million years in age.

3.1 Introductory college science classrooms, non-majors

As a result of our research of petrified wood in informal education sites, the EarthScholars Research Group™ embarked on a longitudinal study of the effectiveness of petrified wood in introductory college geology classrooms in 2004. We also chose petrified wood as a geobiological portal for our Earth Science classrooms because our earlier surveys indicated that petrified wood is a topic to which most students are introduced in the K-12 school environment. Furthermore, students in our Earth History class had previous exposure in their prerequisite physical geology course to famous plant fossils: *Glossopteris* specimens from Australia, South America, India, Africa, and Antarctica provided convincing evidence for the existence of the southern supercontinent Gondwana, whose collision with Laurasia resulted in the formation at Pangaea at the end of the Paleozoic Era. This fossil evidence, as part of the history of science in the development of the plate tectonic theory, is a typical topic of study in most physical geology courses.

We designed and tested the Petrified Wood Survey™ (Appendix A) to probe our students' understanding of geologic time, fossilization processes, and petrified wood's chemistry and geographic occurrences (Clary & Wandersee, 2007). Our investigation was conducted across

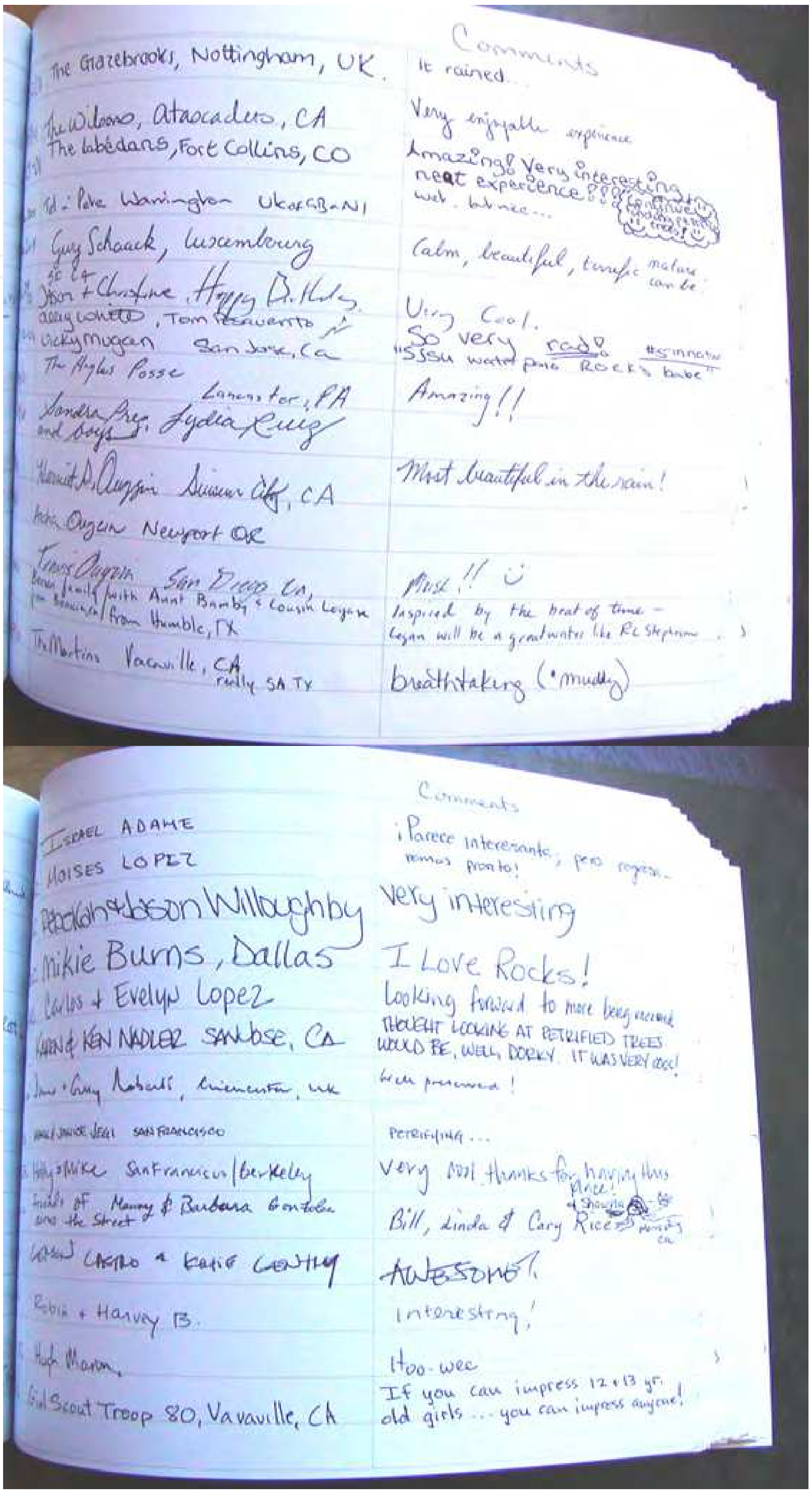

Fig. 3. Sample pages from the Visitors Comments, Petrified Forest, California, attest to visitor interest in the petrified wood display.

three semesters in large, non-science major courses at a research university in the southern US. Through our extended research program, the Petrified Wood Survey™ (PWS) was validated as a testing instrument, and we verified that its use as a pre-survey assessment of incoming student knowledge did not contribute to any testing effect at the end of the semester. The PWS effectively exposed student alternative conceptions about fossilization processes, geologic time, and the formation of petrified wood, as well as the fossils' composition, properties, and geographic occurrence. The PWS also measured significant student gains ($\alpha = 0.05$) between pre- and post-surveys across a semester of Earth History instruction, irregardless of whether petrified wood was included as a geobiological portal in the classroom.

However, the PWS measured even greater student gains in understanding of geologic time, fossilization, and evolution when petrified wood *was* included in the Earth History classroom. During the treatment semester, we integrated hands-on mini-laboratory sessions in which students compared and contrasted (unidentified) fossilized wood and modern log samples, and then discussed and debated the specimens within online discussion groups. Petrified wood specimens from Calistoga, California were incorporated in the classroom, and students also had the option of participating in a petrified wood research project, in which they investigated a unique site where petrified wood was displayed or could be collected.

Our research revealed that the areas of student understanding most affected by petrified wood integration were the abundance of petrified wood, its properties, and the nature of its formation. Other student gains were made in geologic time understanding. From our identification of initial student alternative conceptions, it appears that both weak and strong restructuring of students' conceptual frameworks occurred (Clary & Wandersee, 2007). However, some geochemical content areas were not as affected by petrified wood integration, particularly the role of oxygen (i.e., the lack of oxygen) in fossilization processes, and the role of dissolved minerals in petrified woods' colors.

3.2 Junior level landscape architecture design class

In 2008, we extended our integrated petrified wood study to a junior-level design class at a different US research university in the southern US. Students enrolled in Landscape Architecture Design I were instructed to design an informal educational garden that depicted geological time in front of the campus geosciences building. We predicted petrified wood would be an effective geobiological portal for this assignment, since the design site had an existing petrified log on display that had to be included in each student's final project solution. Students were also familiar with petrified wood: The largest public display of petrified wood east of the Mississippi River is located within the state, and petrified wood is also acknowledged as the state rock. In the university's geology museum, petrified wood is on display, with fairly large trunk segments available for hands-on investigation (Fig. 4.).

We used the Petrified Wood Survey™ to assess design students' incoming knowledge and perceptions, and then utilized it as a posttest to measure any content knowledge gains throughout the project. Although the sample size was small (N = 25), the successful design solutions that effectively depicted geologic time were developed by students who had achieved a minimum geology content knowledge of 75% as measured by the PWS (Clary, Brzuszek, & Wandersee, 2009). The mean gain in geologic content knowledge as measured by the PWS was 3.56, a significant gain that was also higher than the previously reported gains in undergraduate classes for non-science majors (Clary et al, 2009).

Fig. 4. The Dunn-Seiler Museum at Mississippi State University displays several specimens of petrified wood, including this fossilized log that is available for hands-on investigation.

4. Extending petrified wood research to inservice teachers: Methods

Our latest research investigation with petrified wood involves inservice K-12 teachers (N = 97) who self-elected to participate in either a state-funded Mathematics and Science Partnership (MSP) science professional development program (*n* = 28, 41, 18), or a state-funded professional development program for teachers targeted toward improving science instruction in high needs school districts (*n* = 10). Our previous research indicated that non-science majors in introductory college Earth History courses had some familiarity with petrified wood, with only 17-18% of students reporting that they never had been introduced to the topic previously (Clary & Wandersee, 2007). Likewise, our investigation with Landscape Architecture upperclassmen revealed that only 8.3% of students had not received any prior instruction in petrified wood (Clary et al., 2009). Therefore, this current investigation probes the geobiological content knowledge of the inservice teachers who introduce petrified wood in K-12 classrooms. We further implemented hands-on petrified wood and fossilization investigations with some teacher groups (N = 58) and sought teacher feedback as to the activities' effectiveness in the classroom.

In February 2011, the Petrified Wood Survey™ was administered to teachers participating in a MSP program in central Mississippi (*n* = 28). The group is identified in this study as MSP1 . Teachers self-identified that they were primarily K-8 classroom instructors, although one high school teacher (grades 9-12) was present. Following the Petrified Wood Survey™, whole group discussion was conducted on the topic of petrified wood, including some of the alternative conceptions held by teachers and/or students about fossilized wood specimens. Teachers were then divided into five groups (5-6 teachers/group) and provided hand samples of petrified wood and modern wood (Fig. 5).

Fig. 5. Teacher groups were provided hand samples of cut and polished petrified wood (right) and a cut modern log (left) for comparison.

Because not all teachers have direct access to petrified wood samples, we introduced and field-tested a simple activity to mimic the fossilization process that involved Epsom salts and a paper towel. We provided teachers with a simple laboratory procedure from TOPS Learning Systems (n.d.). On a small plate, 14.7 cm^3 of $MgSO_4$ (one level US tablespoon) is dissolved in 29.6 ml (2 level US tablespoons) water. A paper towel is folded into quarters, and then rolled up loosely to form the "log." This paper log is placed in the salt mixture, and allowed to dry over time. The salt solution is drawn into the paper towel log, and the $MgSO_4$ precipitates as the log dries. We previously enlisted middle school students (Fig. 6)

Fig. 6. A middle school student (US grade 7) uses the TOPS Learning Systems (n.d.) petrified paper activity to replicate the fossilization of wood.

to follow the activity sheet procedure, resulting in the "petrified paper logs" that the teachers investigated. Following the investigation of the petrified paper, teachers reflected as to whether this activity would be useful in their science classrooms.

In late February 2011, we investigated a second group of inservice teachers enrolled in a Mathematics and Science Partnership. However, this MSP targets middle school teachers of science, so all participating teachers taught at least one science class at grade 6, 7, or 8. Teachers enrolled in this professional development program, are subdivided into three content areas (chemistry, geosciences, and physics), and rotate through each discipline on an annual basis. We originally engaged these teachers at the conclusion of their first professional development year; this group is identified in this study as TANS1. Therefore, we used the Petrified Wood Survey™ to determine the geobiological content knowledge of the inservice teachers according to the groups they were assigned (chemistry n = 13; geosciences n = 11; physics n = 17). We hypothesized that the teachers who had received instruction in the geosciences may perform better than those teachers who had received instruction in chemistry or physics. Following the survey, teachers returned to their laboratories, and the geosciences teachers formed groups (n = 4) to compare hand samples of petrified wood and modern wood (Fig. 7). Because our original activity implementation with inservice teachers in the earlier group resulted in minimal reflection, we developed a hand-out that provided probing questions on the petrified wood and modern wood hand samples (Fig. 8), and utilized this during the activity. Following this activity, we initiated a whole group discussion on the properties and characteristics of fossilized wood. Teachers then returned to their groups, and investigated the petrified paper laboratory activity (Fig. 9). We developed and included a hand-out that included organizational charts and probing questions for this activity (Fig. 10).

Fig. 7. Teachers in the TANS1 geosciences group compare samples of modern and petrified wood in February 2011.

PW Mini Lab Comparison Questions
1. Which of the specimens is fossilized? How can you tell?
2. What is the composition of each specimen?
3. How are the two specimens alike?
4. How are they different?
5. What process (or processes) was (were) responsible for making the specimens different? How did the fossilized sample form?
6. What do you suspect is the age difference between the two specimens?

Fig. 8. Questions probing the differences between petrified wood and modern wood specimens (Fig. 5) were provided to inservice teachers in the TANS1 geosciences professional development program to facilitate reflection.

In June 2011, we surveyed teachers who participated in a different professional development program, which consisted of four weeks of instruction for the integration of mathematical and science content. Ten elementary teachers participated, and constitute the group ELE1. The Petrified Wood Survey™ was administered, and fossilized and modern wood samples were provided for comparison. Because of time limitations, the full hands-on investigative activities were not conducted.

Fig. 9. Inservice teachers in the TANS1 geosciences group investigate the petrified paper activity. In this photo, teachers are trying to determine why a sample "log" made from coarse brown paper did not dry properly when compared to the petrified paper log.

In June 2011, the TANS professional development group returned to the university campus for an intensive two-week summer academy. Teachers originally in the chemistry group were assigned to geosciences. However, nine of the 2011 TANS geosciences teachers were new recruits. Therefore, the Petrified Wood Survey™ was administered to the new

Petrification Activity Questions
1. Does this activity effectively replicate the fossilization process? (chart provided with Accuracies/Inaccuracies)
2. Can you effectively incorporate this activity into your classroom? (chart provided with Advantages/Disadvantages)
3. Please list the topics/objectives you feel you can address with this activity:
4. Can you modify this activity to address additional topics? If yes, please explain:
5. What required MDE competencies [Mississippi Department of Education science standards] *does this activity address?*
6. What do you predict your student response will be to this activity?

Fig. 10. Organizing charts (questions 1 and 2) and probing questions were provided to inservice teachers in the TANS1 geosciences group to facilitate reflection on the petrification activity.

geosciences group (*n* = 18), referred to in this study as TANS2. Teachers self-organized into four groups, and the petrified wood and modern wood comparison activity was administered using the organizing hand-out (Fig. 8). Following the comparison activity, we initiated whole group discussion on the properties and composition of petrified wood. We concluded the session with the petrified paper activity with small groups, providing the organizational charts and questions (Fig. 10) to facilitate teachers' reflections.

5. Data and analysis

Following our research investigation with our first group of teachers participating in a professional development program (MSP1), we refined the collection instruments for the petrified wood and modern wood comparison activities, and the petrification paper activity. Therefore, in the analyses that follow, we utilize the full data set (N = 97) when comparing the Petrified Wood Survey™ results, as this instrument was consistent throughout our four professional development program investigations (MSP1, TANS1, ELE1, TANS2). However, for the analyses of the petrified wood and modern wood comparisons, and the petrification paper activity, we only utilized the data from MSP1 to inform the development of subsequent investigations. In addition time factors prohibited sufficient data collection from ELE1. The discussion of the two investigative activities, therefore, relies on the data generated from TANS1 and TANS2.

5.1 Petrified Wood Survey™ results for inservice teachers

In our previous research investigations where the Petrified Wood Survey™ (PWS) was utilized, incoming geobiological knowledge on the 12 scored items (questions 3-14, Appendix A) averaged 3.34 (2003 Earth History course for non-science majors), 3.12 (2004 Earth History course for non-science majors), and 3.73 (2008 junior level Landscape Architecture Design I course). All teacher groups performed better than these student averages in our current research investigation. MSP1 (*n* =28) averaged 4.12, while TANS1 (*n* = 41) averaged 4.88 and TANS2 (*n* = 18) averaged 5.00. The smaller group of elementary teachers, ELE1, averaged 3.80 (Table 1).

Furthermore, we were able to separate the discipline averages of TANS1 teacher groups. Although the TANS teachers did not encounter previous instruction that specifically

Group Symbol	Group Description	Number	PWS average
MSP1	K-8 teachers, 1 high school teacher, MSP program	28	4.12
TANS1	6-8 teachers in MSP program	41	4.88
TANS2	6-8 teachers, MSP program 2nd year	18	5.00
ELE1	K-8 teachers, math/ science integrated PD program	10	3.80

Table 1. Average scores on the Petrified Wood Survey™ are organized according to each professional development teacher group.

Group Symbol	Group Description	Number	PWS average
TANS1 – chemistry	6-8 teachers in MSP program	13	4.31
TANS1 - geosciences	6-8 teachers in MSP program	11	5.46
TANS1 - physics	6-8 teachers in MSP program	17	4.94
TANS2 - geosciences	6-8 teachers, MSP program 2nd year	18	5.00

Table 2. Average scores on the Petrified Wood Survey™ are organized according to TANS subgroup.

targeted petrified wood, those TANS teachers who participated in the geosciences content program revealed superior performance with an average PWS score of 5.46. The TANS2 group, with approximately half of the teachers experiencing chemistry instruction the previous year, had the second highest PWS average (Table 2).

We utilized the full set of PWS scores (N = 97) when collecting and analyzing background knowledge for the teachers (Table 3). Most teachers regarded petrified wood as an interdisciplinary topic, although the majority did not think that they had ever had instruction in petrified wood in the K-12 environment before. Only 25% had high school Earth Science instruction, but 43.6% recalled a college course in geology or Earth Science. Few teachers could identify a paleontologist or scientist associated with the study of fossils. The majority of teachers left this item blank, or alternatively wrote the name of the instructor or a famous musician or athlete (e.g., Katy Perry, Lady Gaga). Of the 16 legitimate responses received, only one person was associated with fossils, Roy Chapman Andrews. The highest vote recipients were Charles Darwin and Alfred Wegener. Although Darwin proposed evolution by natural selection, he is not noted for his particular attention to the study of fossils. Wegener, who proposed continental drift, is associated with fossils only as they supported the hypothesis of moving continental masses.

For an in-depth analysis of the different content items of the Petrified Wood Survey™, we opted to analyze and compare the scores on content items of teachers who had previous

Within which school science subject does petrified wood and petrified forests seem to fit best?	
	Percentage
Biology	1.0%
Chemistry	3.1%
Earth Science/Geology	26.8%
Choices Biology/Geology	16.5%
All of the above choices	52.6%
Looking back across all your years in school, how many times were you taught about petrified wood?	
	Percentage
Never	39.4%
Once	33.0%
Twice	14.9%
Three or more times	12.8%
Did you have an Earth Science or Geology class in high school?	
	Percentage
yes	25.3%
no	74.7%
Did you have an Earth Science or Geology class in college?	
	Percentage
yes	43.6%
no	56.4%
*Which famous scientist do you most strongly associate with the study of fossils?**	
	Votes
Roy Chapman Andrews	1
Charles Darwin	5
Albert Einstein	1
Robert Hooke	1
Louis Leakey	1
Alfred Wegener	6

Table 3. Background information from the Petrified Wood Survey™ for all teacher groups (N = 97) revealed an interdisciplinary perception of the petrified wood topic, but little previous instruction. *Few teachers could recognize a famous scientist associated with fossil study. Only 16 legitimate votes were registered.

geoscience instruction (TANS1 geosciences, *n* = 11), teachers with chemistry instruction (TANS2, *n* = 18), and the remainder of teachers in professional development programs (MSP1, TANS1 chemistry, TANS1 physics, ELE1, *n* = 68). We made this decision in an attempt to ascertain whether the professional development program in the geosciences (TANS1 geosciences) had a potential effect on teacher performance. Earlier research investigations also revealed that the most problematic topic areas of petrified wood involved chemical processes (Clary & Wandersee, 2007), and we sought to determine if prior chemistry instruction had potential impact on these teachers' scores (TANS2).

Which of these methods do you think scientists are LEAST likely to use to estimate the age of petrified wood samples?			
	TANS1G	TANS2	Other
Analyzing assoc. fossils of other organisms found surrounding the petrified wood	0%	11%	18%
Analyzing sequence of rock layers in which petrified wood was found	18%	17%	10%
Counting tree rings visible in a stem section	82%	72%	72%
If you held a piece of South African black ironwood (today's heaviest wood) in one hand, and an identically sized piece of petrified wood in your other hand, which do you predict would happen?			
	TANS1G	TANS2	Other
Ironwood would feel heavier.	18%	28%	16%
Petrified wood feels heavier.	45%	56%	37%
Both feel the same.	36%	17%	46%
Which of the following do you think is NOT true of petrified wood?			
	TANS1G	TANS2	Other
It's a fossil.	0%	0%	5%
It's a rock.	45%	39%	36%
It mostly contains ancient wood, plus some minerals.	36%	44%	39%
Many species of petrified plants have been found.	18%	17%	20%

Table 4. Comparison among teacher response percentages for questions probing the properties of petrified wood. TANS1G (*n* = 11) received previous instruction in geosciences, while some participants in TANS2 (*n* = 18) received previous instruction in chemistry. Other teachers (*n* =68) are grouped together for comparative purposes.

Inservice teachers scored well on the methods by which scientists estimate the age of petrified wood samples (Table 4). The teachers with previous geoscience instruction (TANS1 geosciences) and the teachers with previous chemistry instruction (TANS2) performed slightly better on the density of fossilized wood. However, the difference is slight, and not significant. Ironically, although the majority of teachers in TANS1 geosciences acknowledged that petrified wood is of greater density than the world's heaviest wood, they failed to recognize that petrified wood is also a rock. The other teachers performed slightly better on this item. (Table 4).
Questions on the Petrified Wood Survey™ that probed geological content knowledge of the geological time scale and construct of uniformitarianism ("the present is the key to the past") were answered correctly by the majority of the inservice teachers (Table 5).

Which one of these three time periods is the one that occurred longest ago on the geologic time scale?			
	TANS1G	TANS2	Other
Cambrian	64%	56%	49%
Devonian	18%	28%	32%
Jurassic	18%	17%	19%

Someone says, "Today's physical processes, such as those mentioned in the previous question, continue to operate on the earth in the same rate and in the same way as they did in the past." Do you think this is true or false?			
	TANS1G	TANS2	Other
TRUE	64%	72%	51%
FALSE	36%	28%	49%

How long do you estimate it took for a tree from the past to become completely petrified?			
	TANS1G	TANS2	Other
Less than 100 yrs.	9%	11%	24%
Hundreds of yrs.	18%	33%	19%
Thousands of yrs.	36%	22%	26%
Millions of yrs.	36%	28%	28%
Billions of yrs.	0%	6%	3%

Table 5. Comparison among teacher response percentages for questions probing the geological concepts of petrified wood. TANS1G (*n* = 11) received previous instruction in geosciences, while some participants in TANS2 (*n* = 18) received previous instruction in chemistry. Other teachers (*n* =68) are grouped together for comparative purposes.

However, teachers with previous instruction in geosciences (TANS1 geosciences) or chemistry (TANS2) performed slightly better. More problematic was an understanding of the time required for fossilization. The TANS1 geosciences teachers scored slightly higher on this question, but only 36% realized that *millions* of years are typically involved in the fossilization process. However, many teachers in all professional development groups thought that thousands of years, or only hundreds of years, were required. A larger population of inservice teachers outside the geosciences group thought that little time (hundreds of years, or even less than a hundred years) was the required time for the complete fossilization of wood (Table 5).

Perhaps because petrified wood is abundant in the state of Mississippi, the majority of teachers thought that their home state was the site of the largest public display of petrified forests in the US (Table 6). Many inservice teachers also failed to recognize that petrified wood has been found on every continent, even Antarctica.

Teachers who had previous geosciences instruction (TANS1 geosciences) or chemistry instruction (TANS2) performed slightly better in recognizing the conditions necessary for fossilization, and acknowledged that oxygen was detrimental to preservation (Table 7).

To which state would you travel if you wanted to visit the largest public display of petrified forests?			
	TANS1G	TANS2	Other
Arizona	27%	6%	18%
Colorado	0%	6%	12%
Mississippi	73%	56%	51%
New Mexico	0%	6%	3%
Wyoming	0%	28%	16%

Petrified wood has been found			
	TANS1G	TANS2	Other
in a few US states	9%	0%	12%
in a few countries	0%	6%	6%
on a few continents	9%	11%	9%
every continent except Antarctica	55%	33%	37%
on every continent	27%	50%	37%

Table 6. Comparison among teacher response percentages for questions probing petrified woods' geographic locations. TANS1G (n = 11) received previous instruction in geosciences, while some participants in TANS2 (n = 18) received previous instruction in chemistry. Other teachers (n =68) are grouped together for comparative purposes.

However, the TANS2 group appeared to struggle with the role that dissolution (and permineralization) plays in the fossilization of wood.

Similar to our earlier investigations with students with petrified wood, the most difficult PWS questions for inservice teachers were those that probed the chemical composition of

Which of the following do you think is NOT required in order to form petrified wood?			
	TANS1G	TANS2	Other
Dead trees	9%	11%	13%
Rapid burial	36%	39%	53%
O2-rich environment	55%	50%	31%
Time	0%	0%	3%

Which of these natural processes do you think is NOT important to the formation of petrified wood?			
	TANS1G	TANS2	Other
Dissolving	36%	56%	28%
Permeating w/mineral-rich sol'n	9%	0%	9%
Replacing with minerals	0%	6%	12%
Decaying	55%	39%	51%

Table 7. Comparison among teacher response percentages for questions probing the fossilization processes. TANS1G (*n* = 11) received previous instruction in geosciences, while some participants in TANS2 (*n* = 18) received previous instruction in chemistry. Other teachers (*n* =68) are grouped together for comparative purposes.

the fossilized wood (Table 8). Teachers wanted to incorrectly attribute the colors of petrified wood to the original wood color and climate, in addition to the minerals associated with groundwater. Teachers also did not recognize the role of silica (SiO_2) in most petrified wood samples.

What gives petrified wood its colors?			
	TANS1G	TANS2	Other
Climate during fossilization	0%	0%	1%
Minerals assoc. with groundwater	27%	17%	19%
Natural color of original wood	9%	6%	3%
All of the above	64%	78%	76%

With a typical petrified wood sample, what type of mineral has replaced the original wood?			
	TANS1G	TANS2	Other
Carbonate, CaCO3	45%	56%	49%
Phosphate, Ca2(PO4)3	9%	22%	28%
Pyrite, FeS2	9%	11%	14%
Quartz, SiO2	36%	11%	9%

Table 8. Comparison among teacher response percentages for questions probing the chemical composition of petrified wood. TANS1G (*n* = 11) received previous instruction in geosciences, while some participants in TANS2 (*n* = 18) received previous instruction in chemistry. Other teachers (*n* =68) are grouped together for comparative purposes.

5.2 Petrified wood comparisons

Our original group of inservice teachers (MSP1) responded well to the petrified wood and modern wood comparisons. In whole group discussion, teachers identified similarities between samples, as well as contrasting features. Most teachers expressed surprise at our earlier research results, which revealed persistent student alternative conceptions about the age difference between the two samples, and confusion among some students as to which sample was fossilized (Clary & Wandersee, 2007).

With the TANS inservice teachers (TANS1 geosciences, TANS2), we utilized the data collecting hand-out (Fig. 8) to probe teacher perceptions more deeply. We assimilated these two data sets (n = 39), and analyzed the comments via Neundorf's (2002) content analysis guidelines. Persistent themes emerged from teachers' written observations, including 1) samples exhibited similarities with tree rings and preservation of "fibrous" structure; 2) differences included samples' density, composition, and texture; and 3) compositional differences resulted from rock (crystals) and cellulose. Some teachers observed that both specimens were once living plants, but the petrified wood sample had been subjected to additional fossilization processes.

The teachers' comments also revealed several alternative conceptions about fossilized wood. Some teachers did not commit to time differences, reverting instead of "lots of time" and "petrified wood is older," but some teachers (n = 9) persisted in thinking that fossilized wood was only hundreds or thousands of years older than the modern wood sample. Some teachers also exhibited alternative conceptions about the composition, suggesting that fossilized wood was "marble" or that both specimens were made of "carbon."

5.3 Fossilization replication

The first inservice teacher group (MSP1) came to the consensus that the petrified paper activity provided a good simulation of petrified wood formation, but the required drying time would force its use as an exploratory activity before an appropriate science unit was implemented. Several teacher groups suggested incorporating this as a group activity to reduce the space requirement. Another group suggested that measuring activities and comparisons could be incorporated to extend the lesson.

For the TANS inservice teachers (TANS1 geosciences and TANS2), we utilized the data collecting hand-out (Fig. 10) to probe teacher perceptions of this classroom activity. The data sets were combined (n = 39), and teachers' reflections were assimilated and analyzed with Neuendorf's (2002) content analysis guidelines.

Teachers thought that the petrified paper accurately depicted fossilization in that minerals filled in the porous areas of the paper towel similar to a permineralization process; the structure ended up hardened; and the resulting petrified paper did not burn. Teachers noted that the investigation inaccurately portrayed fossilization in that the petrified paper was "not as hard" as petrified wood samples; the minerals did not replace original structures of the paper towel; atmospheric oxygen was present; and there was no burial or pressure. Teachers also pointed out that this process took an extremely short amount of time when compared to natural fossilization processes, and the chemicals involved ($MgSO_4$) were not analogous to the silica of which most petrified wood is composed.

Several classroom advantages were observed, however, including the ease of the activity, the availability of materials, and the ability to modify this process to include different salts, or to extend the activity to include stalactite and stalagmite formation. Several teachers noted that this activity "covers many areas." The primary disadvantages to the petrified paper investigation were the long amount of classroom time needed for the petrified "logs" to dry (which, conversely, might confuse students as to the brevity of the fossilization process), and the use of lighters or matches in the classroom.

The majority of teachers listed scientific investigation, data collection and analysis, and inquiry as topics that were directly addressed by this activity. Many teachers suggested an investigation of other minerals and substrates for classroom-produced "petrified" products. In addition, some teachers noted that this activity could be extended into classroom study of chemical versus physical changes, solutions and solubility, mixtures, elements and compounds, and the Periodic Table. Some of the more unique suggestions included scaffolding into a discussion of the human skeleton and the mineral composition of bones, the progression of life forms (once-living organisms that died and were fossilized), and whether the soaked logs collected by the adventurers in the "Ax Men" show on the History Channel represented petrified samples. Teachers noted that this activity could address required standards in Scientific Inquiry, Earth and Space Science, Physical Science, and Life Science as outlined by the 2010 Mississippi Science Framework (Mississippi Department of Education, 2010).

Finally, teachers' comments were positive as to how their students would receive this activity. One teacher wrote, "Most students will enjoy literally getting their hands wet at the beginning. But to then watch the process over several days and not really 'see' the change occurring from 'wood' to 'rock' until they attempt to light the log. I think there will be some amazed students and some disbelieving students." Other teachers remarked that their students will "be curious as how to change the variables" and that any hands-on investigations were well-received by students.

6. Conclusions and implications

Our previous research confirmed that petrified wood could serve as an effective portal for interdisciplinary study in college science classrooms (Clary & Wandersee, 2007), and re-affirmed the use of the Petrified Wood Survey™ as an instrument to ascertain student understanding of fossilization processes, geologic time, and fossil wood properties (Clary et al., 2009). This latest research extends our previous petrified wood research in that it focuses upon inservice teachers who will, in all likelihood, provide K-12 students with an introduction to petrified wood and the associated scientific constructs that it addresses. Our current investigation probed the geobiological content knowledge of inservice teachers who participated in professional development programs, and sought teacher reflections on the effectiveness and usefulness of petrified wood investigations in the K-12 classroom.

The Petrified Wood Survey™ results revealed that inservice teachers who participated in this investigation (N = 97) performed better than the college students in our previous research studies. This is a positive finding, although we caution that our population is not random, and does not necessarily represent an average teacher performance in the state. Teachers in our investigation elected to participate in science professional development programs, and their geobiological content knowledge may be elevated as a result of this participation.

We found it interesting that, similar to our earlier researched student populations, the most difficult concepts for these inservice teachers were geochemical ones. Few teachers could identify the mineral that replaced the original wood during the fossilization process, and the process that was responsible for the various colors exhibited by petrified wood samples. Few teachers could identify the largest public display of petrified wood in the US, reverting to the largest public display of petrified wood east of the Mississippi River (their own state). Similar to the students we had formerly surveyed, teachers also had difficulties with the role of oxygen (or lack thereof) in the fossilization process. The concepts with which the teachers were most proficient were geologic time, methods by which scientists date fossils, geographic occurrence of petrified wood specimens, and the lack of decay in the fossilization process. Although these teachers performed significantly better than non-science introductory students and junior level design students in their knowledge of fossilization processes, evolution, and geologic time, the majority (56.4%) had never taken a college Earth Science or geology course, and only 25.3% had an Earth Science or geology course in high school! It is also important to note that although the teachers performed significantly better than the college students on the Petrified Wood Survey™, their collective averages—in all professional development groups—were still below the 50% content knowledge level as measured by the PWS. We propose that these findings support the need for science teacher professional development programs in the geosciences.

When we separated scores on the PWS from those teachers with a year of geoscience instruction (TANS1 geosciences, n = 11) from other teacher groups, we observed that the scores for these teachers averaged better than their colleagues. However, we caution that this sample size is small, and does not lend itself to a conclusion as to the effectiveness of the geosciences professional development instruction. Our further analysis of independent items on the PWS did not reveal a remarkable performance of these geosciences teachers on any particular topic. Likewise, an analysis of TANS2 teachers' PWS scores did not reveal superior performance on questions probing the chemical properties of petrified wood, although approximately half of these teachers received professional development in chemistry the previous year. We caution again that our sample size is small (n = 18), and we cannot make conclusions based on these data. However, we think that these data suggest that the chemical concepts involved with petrified wood formation may be best presented in a specialized context of fossilized wood study; if these topics were covered in the chemistry professional development instruction, there does not appear to be transfer of the content knowledge to petrified wood. More research is needed to investigate this possibility.

The comparison activity in which teachers investigated hand samples of petrified wood and modern wood appears to be an effective classroom technique. After our first professional development investigation (MSP1), we suspected that teachers understood the differences between the samples and the processes that had produced them. The use of the data-collecting hand-out in subsequent investigations (TANS1 geosciences and TANS2) was an effective device for recording teacher observations, as well as exposing teacher alternative conceptions. Through the data collected, we learned that some inservice teachers retain alternative conceptions about the length of the fossilization process (hundreds or thousands of years as opposed to millions of years), and the composition of petrified wood (marble, or carbon-based compounds).

Teachers acknowledged that the petrified paper investigation could be an effective tool for demonstrating petrification in the classroom. However, teachers pointed out potential problems with the activity, including classroom time and the use of a lighter and/or matches. These issues can be solved through classroom planning (e.g., initiating the fossil investigation with the petrified paper activity, and returning to the samples at the end of the unit), and/or teacher demonstration (e.g., teachers demonstrate whether or not the petrified paper will burn). Our inservice teachers wisely noted that this activity may foster some alternative conceptions in their students, including the short amount of time for the "fossilization" process, the presence of oxygen, and the lack of burial and pressure. However, the benefits of this activity, and teachers' perceptions that it will be well-received by students, seem to support its classroom incorporation. We suggest that teachers should thoroughly discuss the activity inaccuracies within the classroom, and reaffirm the time and physical factors associated with actual fossilization processes.

Thus far, our research results indicate that petrified wood can serve as an effective geobiological portal to address several important scientific constructs, and that the Petrified Wood Survey™ offers a convenient instrument to identify student and teacher alternative conceptions, and target them with classroom instruction. More research is needed, however. We are currently refining our petrified wood classroom activities so that they can be implemented in K-12 classrooms to effectively address geologic time, fossilization, and evolution, without conveying scientific inaccuracies to students.

7. Appendix A. Petrified Wood Survey™ (©Clary & Wandersee, 2005)

*Where appropriate, correct answers are marked with an asterisk**

1. Looking back across all your years in school, how many times were you taught about petrified wood and petrified forests?
   a. Never
   b. Once
   c. Twice
   d. Three or more times
2. Within which school science subject does the study of petrified wood and petrified forests seem to fit best?
   a. Biology
   b. Chemistry
   c. Earth Science/Geology
   d. Choices A & C
   e. All of the above
3. To which US state would you travel if you wanted to visit the largest public display of petrified forests?
   a. Arizona*
   b. Colorado
   c. Mississippi
   d. New Mexico
   e. Wyoming
4. Petrified wood has been found
   a. In a few US states
   b. In a few countries
   c. On a few continents
   d. On every continent except Antarctica
   e. On every continent*

5. If you held a piece of South African black ironwood (today's heaviest wood) in one hand, and an identically sized piece of petrified wood in your other hand, which do you predict would happen?
   a. The ironwood would feel heavier.
   b. The petrified wood would feel heavier.*
   c. They would seem to be about the same weight.
6. Which of the following do you think is NOT required in order to form petrified wood?
   a. Dead trees
   b. Rapid burial
   c. O_2-rich environment*
   d. Time
7. How long do you estimate it took for a tree from the past to become completely petrified?
   a. Less than 100 years
   b. Hundreds of years
   c. Thousands of years
   d. Millions of years*
   e. Billions of years
8. Which of these methods do you think scientists are LEAST likely to use to estimate the age of petrified wood samples?
   a. Analyzing associated fossils of other organisms found surrounding the petrified wood.
   b. Analyzing the sequence or rock layers in which the petrified wood was found.
   c. Counting tree rings visible in a stem section *
9. Which of these natural processes do you think is not important to the formation of petrified wood?
   a. Dissolving
   b. Permeating with mineral-rich solution
   c. Replacing with minerals
   d. Decaying*
10. Someone says, "Today's physical processes, such as those mentioned in the previous question, continue to operate on earth at the same rate and in the same way as they did in the past." Do you think this is true or false?
   a. True*
   b. False
11. With a typical petrified wood sample, what type of mineral has replaced the original wood?
   a. Carbonate, $CaCO_3$
   b. Phosphate, $Ca_2(PO_4)_3$
   c. Pyrite, FeS_2
   d. Silica/Quartz SiO_2*
12. What gives petrified wood its colors?
   a. Climate during fossilization
   b. Minerals associated with groundwater *
   c. Natural color of original wood
   d. All of the above

13. Which of the following do you think is NOT true of petrified wood?
    a. It's a fossil.
    b. It's a rock.
    c. It mostly contains ancient wood, plus some minerals.*
    d. Many species of petrified plants have been found.
14. Which one of these three time periods is the one that occurred longest ago on the geologic time scale?
    a. Cambrian*
    b. Devonian
    c. Jurassic
15. Did you have an Earth Science or Geology class in high school (grades 9-12)?
    a. Yes
    b. No
16. Did you have an Earth Science or Geology class in college?
    a. Yes
    b. No
17. Which famous scientist do you most strongly associate with the study of fossils?

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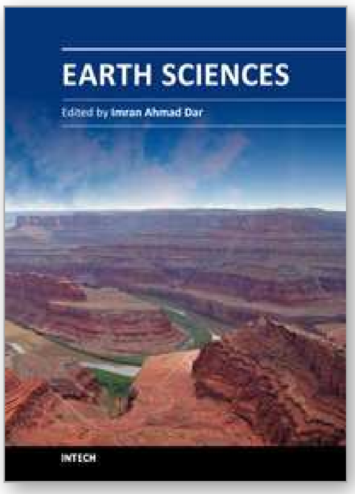

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The studies of Earth's history and of the physical and chemical properties of the substances that make up our planet, are of great significance to our understanding both of its past and its future. The geological and other environmental processes on Earth and the composition of the planet are of vital importance in locating and harnessing its resources. This book is primarily written for research scholars, geologists, civil engineers, mining engineers, and environmentalists. Hopefully the text will be used by students, and it will continue to be of value to them throughout their subsequent professional and research careers. This does not mean to infer that the book was written solely or mainly with the student in mind. Indeed from the point of view of the researcher in Earth and Environmental Science it could be argued that this text contains more detail than he will require in his initial studies or research.

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