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A Compilation and Review of over 500 Geoscience Misconceptions

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This paper organizes and analyses over 500 geoscience misconceptions relating to earthquakes, earth structure, geologic resources, glaciers, historical geology, karst (limestone terrains), plate tectonics, rivers, rocks and minerals, soils, volcanoes, and weathering and erosion. Journal and reliable web resources were reviewed to discover (1) the frequency of misconceptions by subject matter, group (primary, middle-school, high-school, middle-/high-school, college, pre-service teachers, in-service teachers, and undefined) and source (journal versus web); and (2) the pattern of misconceptions across age groups and (3) directions for future research. A total of 502 misconceptions were discovered, with over 40% targeting a middle- and high-school audience. Plate tectonics comprised 19% of all misconceptions, with another 14% and 13% associated with weathering/erosion and historical geology, respectively. Over 80% of all the misconceptions were derived from peer-reviewed journals or web sources, the rest originated from reliable sources on the World Wide Web. The supernatural origin for many of the geoscience phenomena listed here is abandoned by middle school, but in other cases, some misconceptions seem robust through adulthood. Examples of such misconceptions include the origin/pattern of earthquakes, thickness of the earth's crust, oil's origin, movement mechanisms for glaciers, co-existence of humans and dinosaurs, water movement within karst terrains, the nature of plate boundaries, the power of water as an agent of geomorphic change, what constitutes a mineral and a rock, thickness of the soil layer, the distribution of volcanoes, and the difference between weathering and erosion.

Keywords: *Earth science education; Misconceptions*

Introduction

Misconceptions are common within the geosciences and various calls for educational reform have highlighted the need to discover and confront common geoscience

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misconceptions (AAAS, 2012; King, 2010). It is important to address misconceptions in the light of recent literature from cognitive psychology which suggests that students build knowledge based on previously held concepts (Ausubel, 2000; Ausubel, Novak, & Hanesian, 1968; Driver & Erickson, 1983; Patchen & Cox-Petersen, 2008; Powell & Kalina, 2009; Savasci & Berlin, 2012). If the initial concept is faulty, then students will have difficulty developing more sophisticated representations of scientific concepts and it is likely that these faulty ideas can be retained into adulthood.

Dove (1998) outlined many of the causes of misconceptions such as (1) inability to recognize the change: landforms, soils, and rocks are seen as unchanging in students' everyday lives; (2) inadequate prerequisite knowledge: shallow soil profiles are automatically thought to be young (resistant bedrock or slow weathering could create a shallow soil profile that is very old) or that rivers slow down in a downstream direction (does not consider increasing hydraulic radius); (3) the use of everyday language: 'granite' for, instance is applied to all crystalline rocks, the term 'pebbles' applying for everything from gravel to cobbles; (4) oversimplifications: the idea that water always flows downslope when in reality hydraulic pressure can cause water to flow upslope underneath glaciers and in karst (limestone) terrains; (5) similar definitions: 'weather' and 'weathering', so weather must be a cause of weathering; (6) abstract concepts: whether the enormous expanse of deep time or events that are no longer occurring today, like advances of continental glaciers; (7) overlapping concepts: porosity and permeability, earthquakes and volcanoes, cockpit karst and composite volcanoes; and (8) features of similar appearance that have dissimilar origin: cockpit karst and composite volcanoes, confusing sedimentary rock grains with igneous rock crystals. Given the many sources of misconceptions, it is not surprising that these ideas are found in textbooks (King, 2010; Wampler, 1996, 1997), the media (Barnett et al., 2006; Feldman & Wilson, 1998), folklore, the web, and unfortunately, teacher lesson plans.

Research suggests that many educators retain some of the same misconceptions of their students (Happs, 1982; Kusnick, 2002; Oversby, 1996; Schoon, 1992; Trend, 2001). Most educators would acknowledge the importance of addressing their students' faulty concepts, but that is a challenge in today's classroom, where for many K-12 educators, at least, class management issues and just having students read at grade level occupies a great deal of teachers' time. As a result, educators often have little time to discover what geoscience misconceptions actually exist and how these conceptions apply to their curriculum. Furthermore, accessing and organizing misconception resources can be a time-consuming task because useful information is often scattered across a wide variety of scientific journals and throughout the World Wide Web.

While many researchers have devoted themselves to discovering select misconceptions (Clark, Jordan, Kortz, & Libarkin, 2011; Dove, 1998; Gobert, 2000; Kali, Orion, & Eylon, 2003; Sibley, 2005), there has been little in the way of an easy to access summary, both from journals and from reliable sites from the World Wide Web, that would place geoscience misconceptions within easy reach of in-service teachers, pre-service teachers, curriculum developers, students, and of course educational researchers. The purpose of this paper, then, is to organize and analyze over 500 geoscience misconceptions from a broad array of over 70 journal articles and web resources with the goal of providing a comprehensive platform for addressing geoscience misconceptions. The research questions addressed in this paper are:

(1) What is the frequency of misconceptions by subject matter, age level/group, and source? Are some subjects or groups underrepresented? What is the distribution of reported misconceptions across peer-reviewed journals versus web related resources?
(2) To what extent are misconceptions stable though time? That is, do the same misconceptions continue through primary, middle-, high-school, undergraduate and post graduate levels?
(3) Based on the misconception coverage in the literature, what are some directions for future research?

Methods

Selection Process for Misconceptions

For this study, the term 'misconception' (also termed in the literature as alternative conceptions, alternative frameworks, alternative ideas, conceptual misunderstandings, conceptual prisms, erroneous ideas, errors, false ideas, incomplete or naïve notions, intuitive notions, mistakes, misunderstanding, nonscientific beliefs, oversimplifications, preconceived notions, preconceptions and untutored beliefs) was broadly applied to any belief which is contrary to current scientific understanding regarding the topic. Twelve topics common in geoscience textbooks were chosen to organize the misconceptions featured here: earthquakes, earth structure, geologic resources, glaciers, historical geology, karst, plate tectonics, rivers, rocks and minerals, soils, volcanoes, and weathering and erosion. Misconceptions on these topics were discovered from both peer-reviewed journals and from reliable resources from the World Wide Web. The peer-reviewed journal literature was discovered using the following databases: Article First, Applied Science and Technology Abstracts, Agricola, Educational Abstracts, ERIC, Geobase, Georef, General Science Abstracts, Web of Science and Wilson Select. World Wide Web resources were found using the Google Search Engine.

The decision to include web resources was based on the reliable reputation of the web sites such as AAAS, USGS, Smithsonian, Science Education Resource Center and other academically oriented sites. The level of peer review varied for these web sites. For the 'AAAS Project 2061 Science Assessment Website', for example, the review process for listed misconceptions is clearly stated in the 'FAQ' section. Other web sites did not include such evidence, but listed misconceptions seemed reasonable in light of the author's own experience teaching earth science at the college and middle-school levels for over 25 years. There was also the desire to include the broadest possible range of misconceptions for this review. A 'W' will appear after a listed misconception if it was discovered on the web and if the peer review process is not clearly stated.

The misconceptions chosen were recognized by geoscience experts through multiple choice questions, true false, diagramming, open-ended questions administered in a written and oral format and anecdotal observation. If reported, the proportion for a group adhering to a particular misconception is listed as a percentage *after* each misconception. Some misconceptions are stated through anecdotal observation, without necessarily being tested on a target population. There was a tendency of anecdotal misconceptions to be found on the web as opposed to peer-reviewed journals. The notable exception is the extensive collection of peer-reviewed AAAS geoscience misconceptions that appear in a web format only. Anecdotal misconceptions, whether found in journals or on the web, will be flagged in the misconception tables when *no* percentage is placed after listed misconception.

Based on the literature reviewed, eight age/group categories were used to organize the misconception list: primary: K-grade 5 (ages 5–10); middle-school: grades 6–8 (ages 11–13); high school: grades 9–12 (ages 14–17); middle-/high-school grades 6–12; college (age 17+); pre-service teachers; in-service teachers and undefined. The 'middle-/high-school grade 6–12' category was used where the same misconception query was asked for both middle- and high-school students. This was the case for the AAAS survey (2012) featuring misconceptions relating to plate tectonics, weathering/erosion and rivers as well as for Leather's (1987) work on earthquakes and geologic resources. When reported, the first number that appears in parenthesis after the misconception is based on the middle-school sample and the second from the high-school sample. The 'undefined' category was assigned where there was no target audience identified for a particular misconception. However, given the wording and subject matter of 'undefined' misconceptions, it is likely that the target audience was for an educated adult audience.

Potential Biases and Limitations

When setting out to compile this misconception list, it was apparent that there was some subjectivity in reporting the number of misconceptions and in how misconception resources were categorized. The prompts used in various surveys and interviews are oftentimes quite similar in wording. Yet, in order to preserve slight nuances in the meaning of the prompt, each misconception was reported separately. Another reason for reporting all misconceptions was that it provides readers with a number of easy to plug in distracters that can be used to assess students' knowledge using pretests, formative and summative assessments. Still, it must be acknowledged that the total number of misconceptions found—over 500—was more an artifact of how misconceptions were reported rather than an absolute, fixed number of universally accepted misconceptions.

Regarding how misconceptions are categorized: some misconceptions found under 'plate tectonics' in the AAAS list, for example, were placed under the 'Earth Structure' list when 'Earth Layering' was stated in misconception prompt. Similarly, misconceptions found under 'Weathering and Erosion' when referring specifically to rivers, such as 'A small stream cannot wear away the solid rock of a cliff over time', were placed here in the section on 'Rivers'. Furthermore, the section on karst landforms could be placed under 'rocks and minerals', 'weathering and erosion' or even a new section on 'groundwater'.

Results

General Trends

The 502 instances of geoscience misconceptions revealed in this study are categorized in Figure 1. Ninety-three or 19% of misconceptions related to plate tectonics, with another 68 or 14% related to weathering/erosion, and 67 or 13% of misconceptions categorized under historical geology. Figure 1 also compares misconceptions as originating from journals or web sources where the peer review process was not explicitly described. Over 80% of all misconceptions derived from peer-reviewed journals or web sources. Historical geology, Earthquakes, and Glaciers all had a substantial number of misconceptions deriving from such non-peer-reviewed sources. Most of the misconceptions for glaciers came from this category. About 40% of all misconceptions tallied in this study targeted a middle- or high-school audience (Figure 2). College-level misconceptions accounted for 21% of all misconceptions, followed by the Primary-level group (14%).

Earthquake Misconception Trends (50 misconceptions)

Misconceptions on the cause of earthquakes were common for most groups (Table 1). Weather, wind and heat as causes of earthquakes persisted into all age groups. Primary-level students from one Turkish study ascribed earthquakes to supernatural or mythological causes (Simsek, 2007). There is little in the way of misconception research for a primary school population from other countries. By middle school,

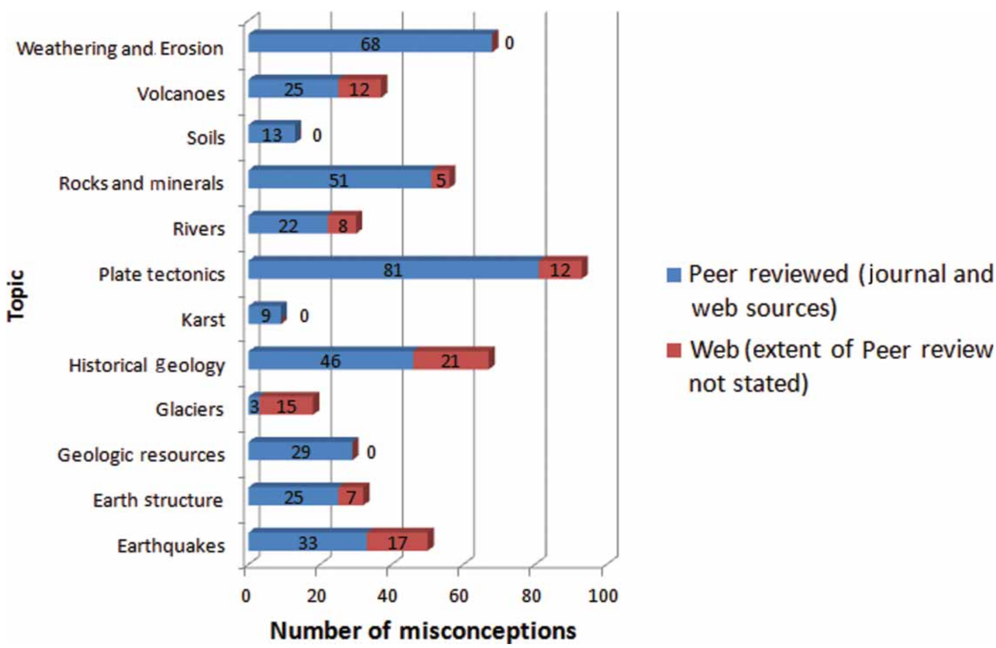

Figure 1. Geoscience misconceptions by topic and by source

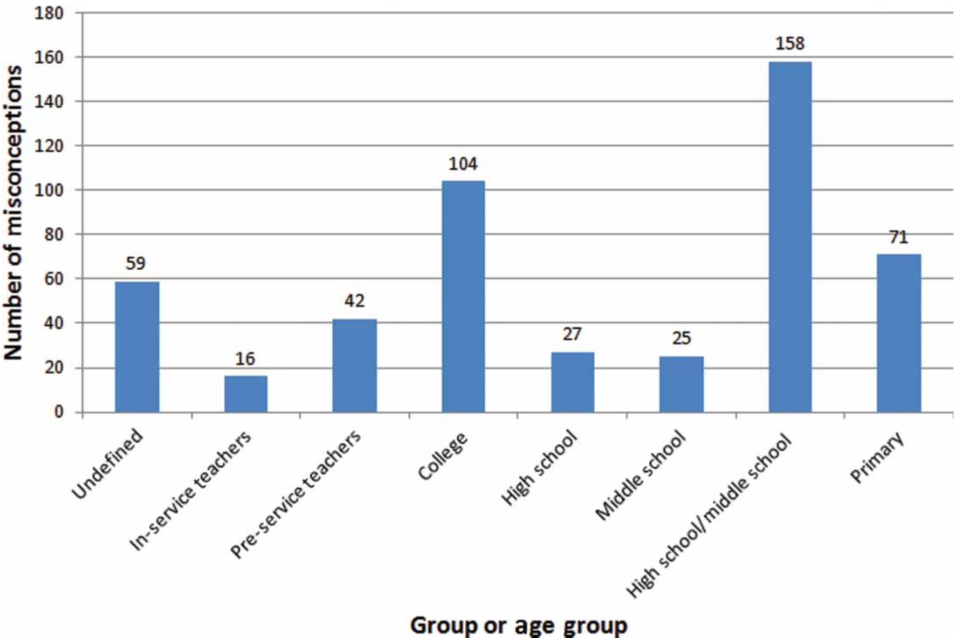

Figure 2. Misconceptions by group or age category sampled

heat and drought are associated with earthquakes. The idea that an earthquake could occur in Chicago or Britain did not seem to decrease with age even though damaging earthquakes can and do occur in these regions.

There was a common idea for all age groups that heat was somehow involved in earthquakes, whether geographically, with earthquakes somehow limited to warm climates, or that heat was a driving force behind earthquakes. The notion that California might fall into the ocean or that huge fissures were generated during temblors has been perpetuated in popular Hollywood movies such as *2012*.

The volcano–earthquake connection is a valid one. Both tend to occur along plate boundaries and the shifting of magma in subterranean chambers beneath volcanoes can produce earthquakes; but the idea that lava emanates from cracks during earthquakes is incorrect. The popular movie *Volcano* erroneously maintains this idea.

One very practical direction for future research could involve addressing misconceptions involving earthquake safety, which could ultimately save lives. One such example would be to 'drop, cover, and hold on' during an earthquake rather than seeking shelter under a doorway as has been previously suggested by students surveyed by Rutin and Sofer (2007).

Earth Structure Misconception Trends (32 Misconceptions)

Common misconceptions across age levels involved the layering, physical state of earth's layers and wave characteristics (Table 2). The correct concentric model for

Table 1. Earthquake misconceptions (50 misconceptions)

Group or age category: undefined (n = 9) ('W' indicates web source where peer review process is not clearly stated)
Cause
Solar flares and magnetic storms cause earthquakes (USGS, 2009) W
Weather triggers earthquakes (USGS, 2009) W
Earthquakes cause volcanoes (USGS, 2009) W
Prediction
Earthquakes can be predicted (USGS, 2009) W
Animals predict earthquakes (USGS, 2009) W
California will fall into the ocean (USGS, 2009) W
Earthquakes are favoured at certain times of day (USGS, 2009) W
General characteristics
Large, deep fissures open when earthquakes occur (USGS, 2009) W
Richter magnitude increases of amplitude involve a linear rather than logarithmic quantity (Krishna, 1994)
Group or age category: pre-service teachers (n = 4)
Prediction
It's impossible that Chicago will be severely damaged by an earthquake in the near future (Schoon, 1992) (31%)
The Midwest in the USA could not be damaged by an earthquake (Phillips, 1991)
Earthquakes can be predicted by animals (12%)
General characteristics
Teachers could not link earthquake distributions to those earthquakes of deep focus origin (King, 2000) (52%)
Group or age category: college (n = 14)
Cause
Earthquakes occur from collapse of subterranean hollow spaces (Kirby, 2011) W
Earthquakes and volcanoes are studied together because both are caused by underground pressure (Barrow & Haskins, 1996) (30%)
Earthquakes and volcanoes are studied together because earthquakes cause volcanoes (Barrow & Haskins, 1996) (17%)
Earthquakes caused by heat, temperature, climate, weather, people, and animals, gas pressure, gravity, the rotation of the Earth, 'exploding soil' or volcanoes (Libarkin, Dahl, Belifuss, & Boone, 2005) (11%)
Wind blowing through subterranean passages causes earthquakes (Kirby, 2011) W
Prediction
Earthquake prediction is possible (Coleman & Soellner, 1995) (64%)
General characteristics
The focus of an earthquake is where all types of waves first emanate (Wampler, 2002)
Seismic waves involve the long distance net motion of particles (Kirby, 2011) W
Seismic waves go from crust to core, but not core to crust (Kirby, 2011) W
S waves (shear waves) do not reach other side of Earth from where earthquake originated because they cannot pass through oceans (Kirby, 2011) W
Earthquakes are rare events (Kirby, 2011) W
The ground cracks opens during an earthquake to swallow people and buildings (Kirby, 2011) W
Earth shaking is deadly (as opposed to building collapse, tsunamis, landslides, fire, etc.) (Kirby, 2011) W

(*Continued*)

Table 1. Continued

The biggest earthquake is a magnitude 10 (Kirby, 2011) W
Group or age category: high school (n = 2)
General characteristics
Aftershocks do not cause additional damage to buildings (Rutin & Sofer, 2007) (50%)
Run outside of school building if earthquake occurs (Rutin & Sofer, 2007) (65% – of those students who ran out of their homes the last time there was an earthquake)
Group or age category: middle school (n = 2)
Earthquakes are causes by changes in gravity or the electromagnetic field (Tsai, 2001)
Earthquakes are due to supernatural forces (Tsai, 2001)
Group or age category: middle/high school (n = 8)
Cause
Heat is the force behind earthquakes (Leather, 1987) (70%) (21–64%)
Hot climate/weather is the force behind all earthquakes (Leather, 1987) (28%)(8%)
Prediction
An earthquake is not possible in Britain (Leather, 1987) (53%) (26–45%)
General characteristics
Most earthquakes occur in only hot climates (Leather, 1987) (55%) (7–62%)
Lava bursts out during an earthquake (Leather, 1987) (17%) (4–14%)
It gets hot during an earthquake (Leather, 1987) (5%)(12%)
Lava flows from the ground during an earthquake (Leather, 1987) (5%) (12%)
Most earthquakes occur in only dry climates (Leather, 1987) (5%) (0%–6%)
Group or age category: primary (n = 11)
Cause
Earthquakes caused because children light a fire and forget it (Simsek, 2007)
Earthquakes occur because God wants it that way (Simsek, 2007)
Earthquakes occur because God is digging with a scoop (Simsek, 2007)
Earthquakes occur because of boiling water underground (Simsek, 2007)
Earthquakes occur because of landslides (Simsek, 2007)
Earthquakes occur because of water coming from underground (Simsek, 2007)
Earthquakes occur because of a flash of lightning (Simsek, 2007)
Earthquakes occur because of storms (Simsek, 2007)
Earthquakes occur because of heavy rains (Simsek, 2007)
Earthquakes occur because of cracking of resources in the underground (Simsek, 2007)
Earthquakes occur because of due to compaction of ground as a result of air pressure (Simsek, 2007)

earth structure seemed to be in place by middle school, but the scale of each layer was confused, with the thickness of the crust being assigned greater thickness than is warranted. Confusion over the driving force behind plate tectonics was reflected in the belief that molten material somehow connected the outer liquid core with crustal dynamics. There was also the persistent misconception that the earth's mantle is semi-liquid or semi-solid when in reality very little is liquid above the mantle at spreading plate boundaries, subduction zones and hot spots. This persistent misconception even extends over to the AAAS site, which stated erroneously (not included here) that 'The layer beneath earth's plates mostly consists of solid rock material', which was identified as a misconception but in reality is actually true. The nature

Table 2. Earth structure misconceptions (32 misconceptions)

Group or age category: in-service teachers (n = 6) ('W' indicates web source where peer review process is not clearly stated)
Teachers who had these concepts 'badly wrong' for (King, 2000)
Earth layers
Width of the crust (King, 2000) (49%)
Physical state
States of the earth, whether solid, partial solid, liquid, with depth (King, 2000) (77%)
Density variations between earth layers (King, 2000) (30%)
Core of earth is liquid or molten (Dahl, Anderson, & Libarkin, 2005) (61%)
Wave characteristics
S wave velocities variations as a function of depth (King, 2000) (34%)
Magnetic field is caused by gravity (Dahl et al., 2005) (34%)
Group or age category: college (n = 12)
Earth layers
Earth's crust is several hundred kilometres thick (Libarkin & Anderson, 2005) (95%)
Earth's crust is several hundred kilometres thick (Steer, Knight, Owens, & McConnell, 2005) (95%)
Crust and lithosphere (or plates) are synonymous terms (Kirby, 2011) W
The interior of the earth can be understood in terms of drilling digging and sonar (Oversby, 1996)
Physical state
Earth is molten except for its crust (Phillips, 1991)
Asthenosphere is liquid (Kirby, 2011) W
Lower mantle is liquid (Kirby, 2011) W
Mantle is predominantly liquid (Clark et al., 2011) (57%)
Earth's core is hollow or that large hollow spaces occur deep within Earth (Kirby, 2011) W
Liquid and solid convection are the same thing within the mantle (Kirby, 2011) W
Wave characteristics
The Earth's core acts like a permanent bar magnet (Kirby, 2011) W
Magnetic reversals can result in mass extinctions and natural disasters (Kirby, 2011) W
Group or age category: high school (n = 3)
Earth layers
Thickness of crust underestimated (King, 2010) (2% out of 531 errors or simplifications found in textbooks from England and Wales)
Physical state
The crust floats on a layer of molten rock called magma (King, 2008)
The mantle is liquid, semi-liquid, or semi-solid (King, 2008)
Group or age category: middle school (n = 5)
Earth layers
Earth has non-concentric layers (Lillo, 1994) (3%–8%)
Physical state
Inner core of the Earth was a liquid rather than a solid (Barnett et al., 2006) (38%)
Fire or lava at the earth's core (Lillo, 1994) (4%–21%)
Soil, rock, or water at earth's core (Lillo, 1994) (3%–17%)
Wave characteristics
The Earth has a magnet at its core (Lillo, 1994) (24%)
Group or age category: middle/high school (n = 1)

(*Continued*)

Table 2. Continued

Physical state	
	The layer beneath the earth's plates mostly consists of a combination of liquid and solid rock (AAAS Project 2061, n.d.) (21%) (18%)
Group or age category: primary (n = 5)	
Earth layers	
	Earth is not differentiated into layers (Sharp, Mackintoch, & Seedhouse, 1995)
Physical state	
	Earth is composed of tarmac, bricks, skeletons, pipes, dead plants, 'old stuff', and centipedes (Sharp et al., 1995)
	It is colder inside the earth because the sun cannot reach it (Sharp et al., 1995)
	The densest layers on the earth is found above the South Pole (Marques & Thompson, 1997a)
Wave characteristics	
	Earth has a magnet at its core (Dove, 1998)

of earth's magnetic field and its relation to the outer core seemed universally misunderstood.

Geologic Resources Misconception Trends (29 Misconceptions)

It was surprising that no studies targeting a college audience were found for geologic resources, particularly oil (Table 3). Perhaps appropriate misconception studies are found in a literature base outside of the education geosciences literature but given the importance of oil to the world's economy, it seems that this could be an important topic for future research. Rule's (2005) and Leather's work (1987) suggested the origin and distribution of oil was confused on many fronts, including time for formation and the source from which it derived. That oil was primarily found in large subterranean caves is aligned with a common groundwater misconception that also states that groundwater derives from underground caves.

Glacier Misconception Trends (18 Misconceptions)

Given that around 30% of the earth's land surface was covered by Pleistocene glaciers, much of this territory now heavily populated, it is surprising that there was not more research on misconceptions relating to glaciers, particularly at the pre-collegiate level (Table 4). Unlike earthquakes, where most misconceptions involved the origin of earthquakes, there was no research into misconceptions on how glaciers form, the types of landforms created and the geographic extent of Pleistocene glaciers. Instead, research across all groups centerd on movement mechanisms, erosion/deposition and some misconception prompts on the relative timing of glacial advance. To date, there are no peer-reviewed journal articles on glacier misconceptions. Given the recent attention devoted to climate change and its impact on the cryosphere, this seems an opportune time for conducting research on glacier misconceptions.

Table 3. Geologic resources (29 misconceptions)

Group or age category: high school (n = 4)
Origin
- Oil derived from animal decay (King, 2010) (3% out of 531 errors or simplifications found in textbooks from England and Wales)
- Oil only formed millions of years ago and is not forming today (King, 2010) (1% out of 531 errors or simplifications found in textbooks from England and Wales)

Distribution
- Ores and minerals are found in deep layers and not in the crust (Lillo, 1994)

General characteristics
- Rocks containing metal compounds are called ores (King, 2010) (2% out of 531 errors or simplifications found in textbooks from England and Wales)

Group or age category: middle school/high school (n = 4) (first number in parentheses is from the middle-school sample, the second, from the high school sample)
Origin
- Oil originates from water (Leather, 1987) (10%) (0–5%)
- Oil forms from coal (Leather, 1987) (1%) (0–10%)

Distribution
- Oil collects in caves under the seabed (16%) (24–35%) (Leather, 1987)

General characteristics
- The world's oil supply will last only 100 years (44%) (30–41%) (Leather, 1987)

Group or age category: primary (n = 21)
Origin
- Oil comes from dinosaurs (Rule, 2005)
- Oil is made from dirt and soil (Rule, 2005)
- Oil forms from molten metal (Rule, 2005)
- Coal comes from rocks (Rule, 2005)
- Coal comes from petroleum or asphalt (Rule, 2005)
- Oil comes from acid rain or rain collected in puddles (Rule, 2005)
- Coal formed from animals (Rule, 2005)
- Fossil fuels can form in a short time (Rule, 2005)

Distribution
- Oil wells are drilled to the center or half way to the center of the Earth (Rule, 2005)
- Oil wells are placed where people are making oil not mining it (Rule, 2005)
- People do not have oil wells in cold places (Rule, 2005)
- Oil fills empty caves, pit, hole, lake, or stream underground (Rule, 2005)
- There is no oil in desert areas (Rule, 2005)
- There is no oil under forests (Rule, 2005)
- Oil is evenly distributed over the Earth (Rule, 2005)
- There is no oil under the ocean (Rule, 2005)

General characteristics
- Natural gas is the same thing as gasoline (Rule, 2005)
- Fossil fuels have been here since the beginning of Earth (Rule, 2005)
- Other than oil spills, oil causes little trouble in the world (Rule, 2005)
- Oil is used mostly for lubrication (Rule, 2005)
- People can find diamonds in coal (Rule, 2005)

Table 4. Glacier misconceptions (18 misconceptions)

Group or age category: undefined (n = 5) ('W' indicates web source where peer review process is not clearly stated)
Movement
Glaciers move primarily by sliding on a lubricated base (Hambrey et al., 2010) W
Contemporary advance of certain valley glaciers indicates that there is no evidence of climate warming (Hambrey et al., 2010) W
Ice sheet discharge and iceberg release are controlled by ancient changes in climate (Hambrey et al., 2010) W
Iceberg calving and calving-related processes do not influence the motion of the interior ice sheet (Hambrey et al., 2010) W
Ice sheets have been stable for long periods of time and are insensitive to changes in climate (Hambrey et al., 2010) W
Group or age category: college (n = 10)
Dating
The 'Ice Ages' happened in the past and are now over (Kirby, 2011) W
There have been only four ice ages (Kirby, 2011) W
The present ice caps have always existed on Earth, although their size has changed through time (Kirby, 2011) W
Movement
Glacial ice moves backwards during glacial 'retreats' (Kirby, 2011) W
Glacial ice is stationary during times when front is neither advancing or retreating (Kirby, 2011) W
Glacial retreat and advance is just motion of whole ice cap back and forth with no significant change in total ice volume (Kirby, 2011) W
Glaciers are only moving ice masses without sediment (Kirby, 2011) W
Erosion/Deposition
Use of 'bulldozer' analogy for glacial movement and sediment transport as opposed to the conveyor belt model (Kirby, 2011) W
Glaciers erode by pushing rocks (Kirby, 2011) W
Glaciers can metamorphose rock (Kirby, 2011) W
Group or age category: high school (n = 1)
Relative dating
The earth was hot when it was formed but it has cooled substantially giving rise to the ice ages (Marques & Thompson, 1997b)
Group or age category: middle school/high school (n = 2) (first number in parentheses is from the middle-school sample, the second, from the high school sample)
Erosion/Deposition
Ice can only break rock when it moves (as in a glacier) (AAAS Project 2061, n.d.) (23%) (18%)
Glaciers cannot break rock (AAAS Project 2061, n.d.) (15%) (13%)

Historical Geology Misconception Trends (67 Misconceptions)

It seemed that most groups had a general idea of important events in geologic time, but placing significant events in the right order remained a challenge (Table 5). In this regard, Trend (2001) reported that relative time is better retained by teachers and is easier to comprehend than absolute time. Pre-service teachers, for example, had problems dating when the first land animals

Table 5. Historical geology (67 misconceptions)

Group or age category: undefined (n = 25) ('W' indicates web source where peer review process is not clearly stated)

Dating

- All radiometric dating is 'carbon dating' (Rowan & Jefferson, 2009) W
- Reversals of the Earth's magnetic field are instantaneous (Rowan & Jefferson, 2009) W
- The Earth is 6–20 thousand years old (Phillips, 1991)

Dinosaurs

- Dinosaurs represent failure and extinction (Smithsonian Institute, 2012) W
- Dinosaurs died out because they were unsuccessful in evolutionary terms (Pickrell, 2006) W
- Dinosaurs and 'humans' coexisted (Smithsonian Institute, 2012) W
- Humans lived alongside dinosaurs (Pickrell, 2006) W
- Dinosaurs were either all hot-blooded or all cold-blooded (Smithsonian Institute, 2012) W
- The word dinosaur means 'terrible-lizard.' (Smithsonian Institute, 2012) W
- Dinosaurs all lived and died at the same time (Smithsonian Institute, 2012) W
- All dinosaurs died out 65 million years ago (Pickrell, 2006) W
- An asteroid (or comet) killed the dinosaurs (Smithsonian Institute, 2012) W
- Mammals arose after the dinosaurs, and helped drive the dinosaurs into extinction by eating dinosaur eggs (Smithsonian Institute, 2012) W
- Mammals only came into being after the dinosaurs died out (Pickrell, 2006) W
- All big reptiles from the prehistoric past ('Monsters') are dinosaurs (Smithsonian Institute, 2012) W
- Archaeologists dig up dinosaurs (Smithsonian Institute, 2012) W
- Dinosaurs died out because mammals ate their eggs (Pickrell, 2006) W
- An asteroid impact alone killed the dinosaurs (Pickrell, 2006) W
- Dinosaurs were slow and sluggish animals (Pickrell, 2006) W
- All large land reptiles from prehistoric times were dinosaurs (Pickrell, 2006) W
- Marine reptiles—for example, plesiosaurs and ichthyosaurs—were dinosaurs (Pickrell, 2006) W
- Flying reptiles were dinosaurs (Pickrell, 2006) W
- Dilophosaurus spat acidic poison, had colorful frills, and was the right size as depicted in Jurassic Park (Feldman & Wilson, 1998)
- Velciraptors had the intelligence of a chimpanzee (Feldman & Wilson, 1998)
- Godzilla was an amphibian (Feldman & Wilson, 1998)

Group or age category: in-service teachers (n = 4)

Dating

- One-celled organisms were present when the earth first formed (Dahl et al., 2005) 66%
- Events that teachers had misconceptions regarding placement in the correct sequence: Atlantic Ocean begins to form, dinosaur extinction, first appearance of humans, extinction of mammoths (Dahl et al., 2005)

Dating techniques

- Carbon in rock is the most accurate dating method (Dahl et al., 2005) (48%)
- Mountain height can be used to age the earth (Dahl et al., 2005) (33%)

Group or age category: pre-service teachers (n = 9)

Dating

- The sun formed before the 'Big Bang' not recognized as the beginning of space and time (Trend, 2001)
- Earth and life originated simultaneously (Trend, 2001)
- Pangea fragmentation occurred before the appearance of trees and the appearance of organisms with hard parts (Trend, 2001)
- Humans originated after the demise of the mammoths (Trend, 2001)

(*Continued*)

Table 5. Continued

One celled organisms were present when the earth first formed (Dahl et al., 2005) 64%
Humans and dinosaurs lived at the same time (Schoon, 1995) (19%)
Dating techniques
Carbon in rock is the most accurate dating method (Dahl et al., 2005) (38%)
Mountain height can be used to age the earth (Dahl et al., 2005) (33%)
Fossils
Only living things like plants and animals that have undergone fossilization are considered fossils. An unfossilized shark tooth or track would not be considered a fossil (Oversby, 1996)
Group or age category: college (n = 15)
Dating
Simple, one-celled organisms existed when the Earth first formed (Libarkin & Anderson, 2005) (47% pre-test, 43% after instruction)
Dinosaurs came into existence about halfway through geologic time (Libarkin & Anderson, 2005) (37% pre-test, 40% after instruction)
A single continent existed when humans first appeared on Earth (Libarkin & Anderson, 2005) (52% pre-test, 47% after instruction)
The Earth is less than 4–5 billion years old (50%–90%) (Libarkin et al., 2005)
A meteorite impact caused the Earth to have a tilt in its axis (Raia, 2005)
Glaciation is monocausal, only due to a change in tilt of the Earth, or ocean circulation, or plate tectonics, (Raia, 2005)
Using the law of superposition, a stratigraphic column is not the result of a dynamic system (Raia, 2005)
Many events such as depositional sequences are monocausal (Raia, 2005)
Dating techniques
Fossils, rock layers, and carbon are the most accurate method of assessing the earth's age (Libarkin & Anderson, 2005) (78% pre-test, 72% after instruction)
Uniformitarianism
Uniformitarianism is unique to geology (Shea, 1982)
Uniformitarianism holds that only currently acting processes operated during geologic time (Shea, 1982)
Uniformitarianism holds that the rates of processes have been constant (Shea, 1982)
Uniformitarianism holds that only gradual processes have acted and that catastrophes have not occurred during Earth's past (Shea, 1982)
Uniformitarianism holds that conditions on Earth have not changed much (Shea, 1982)
Uniformitarianism holds that the laws governing nature have been constant through time (Shea, 1982)
Group or age category: high school (n = 3)
Dating
Geologic deposition occurs at a uniform or linear rate (Dodick & Orion, 2003)
Dinosaurs and cavemen lived at the same time (Phillips, 1991)
Fossils
Fossils always evolve to structures of greater complexity (Dodick & Orion, 2003)
Group or age category: middle school (n = 8)
Dating
Sun formation occurred before the 'Big Bang' (Trend, 1998)
The first volcano and first rocks occur far apart in regard to time (Trend, 1998)
There is a big time gap between the formation of the earth and the formation of first rocks (Trend, 1998)

(*Continued*)

Table 5. Continued

The first volcanoes occur close in time to the dinosaurs' extinction (Trend, 1998)
Dinosaurs and cavemen lived at the same time (Phillips, 1991)
Geological events can be classified into two main categories, 'extremely ancient', and 'less ancient.' (Trend, 1998)
It is possible to estimate the age of an outcrop based only on its size and number of layers (67%) (does not take into account weathering erosion and disconformities) (Dodick & Orion, 2003)
Fossils
Different fossils can be aged by their complexity with more complex fossils being younger (Dodick & Orion, 2003)
Group or age category: middle/high school (n = 1)
Dating
All mountains that exist today formed when the earth first formed (AAAS Project 2061) (10%) (7%)
Group or age category: primary (n = 2)
Relative age dating
Color indicates rock age (Ault, 1982)
Rocks that are more crumbly are older (Ault, 1982)

appeared, the extinction of trilobites, the separation of the Atlantic Ocean, the ice age and the demise of mammoths. Teachers and other groups generally simplified geologic time's complexity by creating an extremely ancient, moderately ancient time and less ancient recent time. While some misunderstandings diminish with age, many were held right through adulthood and this is supported by the common misconception that humans and dinosaurs coexisted. Although peer-reviewed literature was common for dating, there was little in the way of student surveyed peer-reviewed dinosaur misconception research for a K-12 population. Given that many K-12 students have been exposed to the *Jurassic Park* movie series, it seems dinosaur misconception research would yield good insight into the thinking of this population.

Karst Misconception Trends (9 Misconceptions)

Karst landscapes cover around 10–15% of the earth's surface yet the misconception literature is largely devoid of karst misconceptions. There appears no literature at the primary, middle, high school, or college levels devoted to this important landscape type (Table 6). Understandably, karst landscapes do not erupt, shake or are commonly depicted in major motion pictures; hence, karst misconception research may lack the appeal of volcanoes, earthquakes or dinosaurs. Nonetheless, students have a natural curiosity about caves and when sinkholes swallow residential neighborhoods. The question is what misunderstandings do students have about karst?

Table 6. Karst misconceptions (9 misconceptions)

Group or age category: undefined (n = 8)
Water movement
Pre-existing sinkholes are present to serve as conduits for infiltrating water (Kastning & Kastning, 1999)
Karst groundwater flow is the shortest route between two points (Kastning & Kastning, 1999)
Pollutants discharged into karst remain stationary (Kastning & Kastning, 1999)
Karst spring water is pure (Kastning & Kastning, 1999)
General characteristics
Karst is always easy to see expressed on the surface (Kastning & Kastning, 1999)
A landscape lacking in caves means the area is not a karst terrane (Kastning & Kastning, 1999)
Caves are the same age as the bedrock from which they are formed (Kastning & Kastning, 1999)
Bedrock exists without voids, strong, unyielding, and stable (Kastning & Kastning, 1999)
Group or age category: college (n = 1)
Water movement
Water always flows downslope (Nelson, Aron, & Francek, 1992)

Plate Tectonics Misconception Trends (93 Misconceptions)

The study of plate tectonics is a cornerstone in the geoscience curriculum and with the inclusion of AAAS peer-reviewed resources, the 93 misconceptions listed provide a detailed view of student thinking (Table 7). There appeared to be a poor understanding of the nature of plate boundaries, how fast plates move, and the role of heat in driving plate movement. Further confusion existed on how the ductile nature of plates results in orogeny. Finally, students were uncertain as to how plates were expressed at the surface, with many believing plates were only composed of crust as opposed to crust plus the upper portion of the lithosphere.

River Misconception Trends (30 Misconceptions)

For all groups, it appeared that the power of water as an agent of geomorphic change was not grasped (Table 8). A common theme was the idea of stasis, that fluvial landforms, created by erosion and deposition, do not fundamentally change as a function of time. Valleys were recognized as a feature in the landscape but valleys were thought to have existed before rivers with little connection made between process and landform. It is also worth noting that there was little in the way of peer-reviewed literature at the college level on misconceptions associated with rivers. Like with misconceptions associated with earthquakes and rocks and minerals, river formation for primary school children was attributed to supernatural or mythical forces.

Rock/Mineral Misconception Trends (56 Misconceptions)

An evolution takes place from primary age levels where rocks were thought to be created by supernatural forces or by humans to the later primary years where Piaget (1929) found that students believed rocks were created through natural forces. By middle

Table 7. Plate tectonic misconceptions (93 misconceptions)

Group or age category: in-service teachers (n = 3) ('W' indicates web source where peer review process is not clearly stated)

Origin

- Could not correlate high and low heat flow to mid-oceanic ridges and subduction zones (King, 2000) (25%)
- Magma from plate melting and from the mantle plumes originate similarly (King, 2000)
- Heat flow beneath plates is uniform (King, 2000)

Group or age category: college (n = 21)

Origin

- Melting occurs at the subducting plate (as opposed to the nearby mantle wedge) (Clark et al., 2011) (35%)
- Melting occurs at subsurface plate boundaries because of temperature or heat (as opposed to depressurization or dewatering) (Clark et al., 2011) (31%)
- Melting occurs due to rocks or plates moving or crashing together (Clark et al., 2011) (14%)
- Magnetic polar wandering causes plate tectonics (Marques & Thompson, 1997a)
- Oceans are responsible for oceanic crust (Kirby, 2011) W
- Over time there has been no significant change in ratio of oceanic to continental areas (Kirby, 2011) W

Thickness and location

- Tectonic plates are somewhere below the surface (Libarkin & Anderson, 2005) (56% pre-test, 46% after instruction)
- Coastlines are plate boundaries (Marques & Thompson, 1997a) (20%)
- Plates rotate around an axis (Marques & Thompson, 1997a)
- Continental 'shelves' are similar to shelves in homes, extend out over edge of continent and can break and collapse to form tsunamis (Kirby, 2011) W

Plate boundaries

- A plate boundary type is the same thing as a plate (Kirby, 2011) W
- The edge of a continent is the same thing as a plate boundary (Kirby, 2011) W

Movement

- Only continents move, not oceans (Kirby, 2011) W
- Plate movement is imperceptible on a human timeframe (Kirby, 2011) W

Plate divergence

- Convergence occurs at mid-oceanic ridge boundaries rather than divergence (Clark et al., 2011) (25%)
- Divergent ocean ridges are due to vertical uplift or convergence, rather than divergence (Kirby, 2011) W
- Present oceans only began as Pangea broke apart—tied to general idea that Pangea was the original continent at the Earth's start (Kirby, 2011) W
- Rifting can divide families or separate a species from its food source (Kirby, 2011) W
- Apart from differences due to changes in ice volume, sea level has remained relatively constant through time (Kirby, 2011) W

Plate convergence

- Most crust motions are due to vertical motions, not lateral (Kirby, 2011) W
- Vertical rather than horizontal movements result in continents (Marques & Thompson, 1997a)

Group or age category: middle school/high school (n = 67) (first number in parentheses is from the middle-school sample, the second, from the high school sample)

Plate composition

- Plates are made of melted rock (AAAS Project 2061, n.d.) (40%) (39%)

(*Continued*)

Table 7. Continued

Plates described as composed of crust (King, 2000, 2008, 2010) (5%) out of 531 errors or simplifications found in texbooks from England and Wales)
Earth's plates are made of sand (AAAS Project 2061, n.d.) (10%) (8%)
The solid rock of a cliff is not a part of a plate (AAAS Project 2061, n.d.) (31%) (30%)
Ocean basins are not part of earth's plates (AAAS Project 2061, n.d.) (25%) (23%)
Continents are on top of plates but are not part of plates (AAAS Project 2061, n.d.).(22%) (24%)
Continents are not part of earth's plates (AAAS Project 2061, n.d.) (20%) (18%)
Continents are next to plates but are not part of plates (AAAS Project 2061, n.d.) (12%) (11%)
Thickness and location
Earth's plates are located deep within the earth and are not exposed at the earth's surface (AAAS Project 2061, n.d.).(53%) (52%)
Deepest part of the ocean is in the center and the highest part of the continents is in the center (Marques & Thompson, 1997b) (45%)
Plates are feet thick (AAAS Project 2061, n.d.).(49%) (43%)
Plates are several inches thick (AAAS Project 2061, n.d.) (12%) (10%)
Earth's plates are piled on top of each other (AAAS Project 2061, n.d.) (27%) (29%)
Continents sit on top of a layer of water, and the water is above a plate (AAAS Project 2061, n.d.) (25%) (21%)
Number of plates
The earth has seven plates (AAAS Project 2061, n.d.) (31%) (28%)
The earth has one very large plate (AAAS Project 2061, n.d.) (7%) (7%)
The earth has about one hundred plates (AAAS Project 2061, n.d.) (23%) (22%)
There is one continent on each plate (AAAS Project 2061, n.d.) (31%) (28%)
Plate boundaries
Earth's plates are separated by empty gaps (AAAS Project 2061, n.d.) (29%) (40%)
Plate boundaries only occur where continents meet ocean basins (AAAS Project 2061, n.d.) (22%) (24%)
Earth's plates are not in contact with each other (AAAS Project 2061, n.d.) (24%) (20%)
Earth's plates are separated from each other by oceans (AAAS Project 2061, n.d.) (15%) (16%)
Plate boundaries are always found in the middle of ocean basins (AAAS Project 2061, n.d.) (16%) (12%)
Earth's plates are surrounded by melted rock so that the plates are not touching each other (AAAS Project 2061, n.d.) (15%) (11%)
Plate material does not get removed from the edges of plates (AAAS Project 2061, n.d.) (11%)
Plate boundaries cannot occur within a continent (AAAS Project 2061, n.d.) (11%) (9%)
Movement
Continents only move inches over hundreds of years, not feet or miles (AAAS Project 2061, n.d.) (34%) (39%)
Continents and ocean basins move, but so slowly that they will barely have moved after hundreds of years (AAAS Project 2061, n.d.) (34%) (39%)
Earth's plates move by floating on a layer of melted rock (AAAS Project 2061, n.d.) (33%) (38%)
Continents would only move inches over millions of years, not feet or miles (AAAS Project 2061, n.d.) (31%) (33%)
Ocean basins do not move (AAAS Project 2061, n.d.) (29%) (30%)
Ocean basins move separately from earth's plates (AAAS Project 2061, n.d.) (27%) (25%)
Plates move when the layer below them temporarily melts and moves (AAAS Project 2061, n.d.) (22%) (21%)

(*Continued*)

Table 7. Continued

The entire layer beneath the earth's plates moves in one direction (AAAS Project 2061, n.d.) (19%)
Continents move so slowly that even after millions of years the distance they moved cannot be measured (AAAS Project 2061, n.d.) (17%) (17%)
The layer beneath the earth's plates moves very rapidly (AAAS Project 2061, n.d.).(15%) (15%)
The layer below the earth's plates does not move (AAAS Project 2061, n.d.) (16%) (12%)
Earth's plates move several feet per year (AAAS Project 2061, n.d.) (18%) (14%)
Continents move miles over hundreds of years (AAAS Project 2061, n.d.) (19%) (14%)
Continents move separately from earth's plates (AAAS Project 2061, n.d.) (15%) (14%)
Continents do not move (AAAS Project 2061, n.d.) (13%) (10%)
Earth's plates move several miles per year (AAAS Project 2061, n.d.) (11%) (10%)
A continent would not move at all over 100 years (AAAS Project 2061, n.d.) (10%) (9%)
Earth's plates do not move (AAAS Project 2061, n.d.) (8%) (8%)
Ocean basins moved in the past, but they are no longer moving (AAAS Project 2061, n.d.) (10%) (6%)
Continents moved in the past, but they are no longer moving (AAAS Project 2061, n.d.) (11%) (5%)
The plates do not move because they sit on a layer of solid rock (AAAS Project 2061, n.d.) (6%) (5%)
Mountains are rapidly created (Phillips, 1991)
Plate convergence
Earth's plates cannot bend (AAAS Project 2061, n.d.) (50%) (45%)
Mountains form by the piling up of pieces of rock (AAAS Project 2061, n.d.) (50%) (45%)
Continental plate material is only pushed upward when it pushes into continental plate material on another plate (AAAS Project 2061, n.d.) (37%) (35%)
When two plates push together and continental plate material is at the edge of both plates, one plate will stop moving and the edge of the other plate will be pushed upward (AAAS Project 2061, n.d.) (22%) (23%)
Continental plate material is pushed beneath oceanic plate material when two plates push together (AAAS Project 2061, n.d.) (25%) (22%)
When a plate with continental plate material at its edge pushes into another plate, the continental plate material is always pushed downward (AAAS Project 2061, n.d.) (15%) (18%)
When two plates push into each other, both plates will stop moving (AAAS Project 2061, n.d.) (20%) (17%)
When two plates push together, the edges of the plates break into small pieces (AAAS Project 2061, n.d.) (16%) (15%)
When two plates push together and continental plate material makes up the edge of both plates, both plates will be pushed downward (AAAS Project 2061, n.d.) (15%) (13%)
New mountains developed in the past, but no new mountains are developing today (AAAS Project 2061, n.d.) (13%) (12%)
There have been times when mountains have developed in the past, but only occasionally (i.e. not continuously) (AAAS Project 2061, n.d.) (14%) (10%)
When two plates push into each other, both plates will stop moving (AAAS Project 2061, n.d.) (9%) (9%)
Plate divergence
When two plates move away from each other, loose rock material fills the empty gap that forms between them (AAAS Project 2061, n.d.) (28%) (25%)

(*Continued*)

Table 7. Continued

When two plates move away from each other, loose rock material fills the empty gap that forms between them (AAAS Project 2061, n.d.) (24%)
The amount of plate material that is added to the edge of a plate is balanced by the amount of plate material that is removed by being broken into pieces and carried away (AAAS Project 2061, n.d.) (28%) (24%)
When two plates move away from each other, water fills the empty gap that forms between the plates (AAAS Project 2061, n.d.) (24%)
When two plates move away from one another, an empty gap forms between them (AAAS Project 2061, n.d.) (22%) (21%)
New plate material cannot be added to the edges of plates (AAAS Project 2061, n.d.) (20%) (19%)
New plate material forms where continents meet ocean basins, not where two plates move apart (AAAS Project 2061, n.d.) (17%) (18%)
Group or age category: primary (n = 2)
Origin
Mountains are created by God or man (Piaget, 1929)
Mountains grow from stones, molded from dirt (Piaget, 1929)

school, students became familiar with the rock cycle but even here there were many misunderstandings of the rock cycle with students not making linkages between internal and external processes (Table 9). The rock cycle has great explanatory power for addressing many of these misconceptions but as Kali et al. (2003) pointed out, students had difficulty in seeing connections between the three major rock categories. Indeed, rather than being seen as showing relationships between rock classes, the rock cycle was seen as the cause of rock formation (Ford, 2005).

What constituted a rock and mineral was widely misunderstood by all age groups. Given the wide variety of forms in which rocks and minerals appear, it is to be expected that there were many misconceptions about the classification and genesis of rocks and minerals. Sensory-based rock characteristics such as color, shape and size were often used by students to identify rocks when in reality these characteristics were of limited use in rock identification. Dove (1996) concluded that if a student's perception of a rock, memorized or from prior experience, is not met, it will go unrecognized (Dove, 1996, 1998). Another factor limiting misconception free rock identification is the failure to stress the gradational nature of the rock classification system; consequently, it is no wonder that students are poor at classifying rocks.

Soil Misconception Trends (13 Misconceptions)

There was student ambiguity over what actually makes up soil and how long it takes soil to form (Table 10). Like river valleys, soils were seen as unchanging. Students of all ages had a tendency to call soil 'dirt', which assigns it a negative context rather than thinking of soil and the crucible of life upon which all agricultural production relies. Like layering misconceptions associated with the structure of the earth, there was uncertainty regarding the depth to which soil extends. Soils' depth for primary

Table 8. Rivers misconceptions (30 misconceptions)

Group or age category: pre-service teachers (n = 1) ('W' indicates web source where peer review process is not clearly stated)

Flooding

Flooding occurs only in the spring, after the winter snow melt (Schoon, 1995) (16%)

Group or age category: college (n = 8)

Erosion

Rivers do not carve valleys, but only passively flow down them (Kirby, 2011) W

Although rivers can cut down over time, they do not cut to the sides (inadvertently aided by widespread attention paid to Grand Canyon, and goosenecks in earth science texts) (Kirby, 2011) W

Waterfalls can increase in height over time, but do not retreat (Kirby, 2011) W

Transport and flow direction

Streams are simply flowing water (with little to no concept of sediment movement) (Kirby, 2011) W

Rivers flow south—sometimes modified to rivers in northern hemisphere flow south, while those in southern hemisphere flow north (Kirby, 2011) W

Flooding

Concept of 30-year, 100-year, 500-year floods meaning set time intervals between events, rather than water heights (Kirby, 2011) W

Idea that human activities cannot affect geological processes like river flow, flood cycles, etc. (Kirby, 2011) W

Floods are rare, atypical, almost unnatural events rather than normal river behaviour (Kirby, 2011) W

Group or age category: middle school/high school (n = 10) (first number in parentheses is from the middle-school sample, the second, from the high school sample)

Erosion

Water can wear down the solid rock of a river valley only a small amount (feet or inches) over millions of years (AAAS Project 2061, n.d.) (54%) (52%)

Moving water can only wear down solid rock over long time periods. Changes are not happening over short time periods (i.e. a day or a year) (AAAS Project 2061, n.d.) (42%) (47%)

A small stream cannot wear away the solid rock of a cliff over time (AAAS Project 2061, n.d.) (36%) (34%)

Moving water can only change the surface of the earth over long-time periods. Changes are not happening over short-time periods (i.e. a day or a year) (AAAS Project 2061, n.d.) (33%) (27%)

Water cannot break rocks (AAAS Project 2061, n.d.) (26%) (26%)

Wind and water cannot wear away solid rock to change the path of a river (AAAS Project 2061, n.d.) (23%) (22%)

Water cannot make a valley deeper (AAAS Project 2061, n.d.) (15%) (15%)

Moving water cannot wear down solid rock (AAAS Project 2061, n.d.) (8%)

Moving water cannot wear away solid rock to change the shape of a valley (AAAS Project 2061, n.d.) (4%) (8%)

Transport and flow direction

Water cannot carry rocks and deposit them in a new location (AAAS Project 2061, n.d.) (23%) (22%)

Group or age category: primary (n = 11)

Origin

Rivers are dug out by God or man (Dove, 1998)

Towns were there before rivers (Dove, 1998)

(*Continued*)

Table 8. Continued

Erosion	
	The Grand Canyon was carved by people at war, fairies, or other supernatural explanation) (Martinez, Bannan, & Kitsantas, 2012) (29%)
	Erosion only occurs while rain is falling (Martinez et al., 2012) (24%)
	Accumulation rather than erosion formed all landforms (Martinez et al., 2012) (18%)
	Erosion as a finished process (Martinez et al., 2012) (10%)
Transport and flow direction	
	Forces others than gravity cause water to move (Martinez et al., 2012) (12%)
	Path of river cannot start from a plain (Martinez et al., 2012) (12%)
	River flow is caused by people swimming or rowing (Dove, 1998)
	River flow is causes by the wind (Dove, 1998)
	Rivers flow inland from the sea (Dove, 1998)

through high school was believed to extend for miles beneath the surface. Observing fresh soil profiles, like viewing tectonic plates or earth structure, is not easy; hence it is not surprising that there was difficulty with understanding soils. Finally, there was little connection made between rocks as parent material and the formation of soil. Given soil's importance, research on soil misconceptions is warranted to improve our appreciation of this delicate resource, particularly at the college level.

Volcano Misconception Trends (37 Misconceptions)

A persistent misconception was that volcanoes were found mainly located in hot climates in terrestrial environments, excluding the many volcanoes found in temperate or frigid zones as well as volcanoes found on the ocean floor (Table 11). The magma supplying the lava for volcanoes was thought to originate deep in the earth's core as opposed to the upper mantle. Like with soil misconceptions, there was little in the way of middle- and high-school-level misconception research devoted only to volcano morphology. With regard to form and eruption style, many groups believed that all volcanic eruptions were violent and were accompanied by lava. College students were unfamiliar with secondary hazards as the main cause of death and injury from volcanic eruptions and it seems fair that future studies would also find this to be the case at the K-12 level.

Weathering and Erosion Misconception Trends (68 Misconceptions)

There were numerous misconceptions relating to weathering and erosion (68), second only to the number of misconceptions associated with plate tectonics (93) (Table 12). There was the tendency to incorrectly associate erosion with weather phenomena and to equate weathering as synonymous with erosion; namely, that both involve movement. The consensus view on weathering is that it involves the breakdown of bedrock and other material *in situ*, whereas erosion involves the movement of material broken down in place. There was a general reluctance to accept the effectiveness of

Table 9. Rock and mineral misconceptions (56 misconceptions)

Group or age category: pre-service teachers (n = 26) ('W' indicates web source where peer review process is not clearly stated)
Minerals
If a crystal scratches glass it is a diamond (Schoon, 1995) (16%)
Quartz is a rock (Dove, 1996) (14%)
Minerals are associated with mineral, vitamins, and mineral resources (Happs, 1982)
All minerals are created under pressure (Oversby, 1996)
Origin
Rocks form when pebbles break off from outcrops and become rounded (Kusnick, 2002)
Rocks are formed by catastrophic events (Kusnick, 2002)
Rocks form under short time spans (Kusnick, 2002)
Glaciers form rocks (Stofflett, 1994)
Stone quarried is not 'natural' and therefore not a rock (Dove, 1996)
Igneous rocks
Granite is marble or quartz because 'it glistens' (Dove, 1996) (18%)
Heat at the surface is sufficient to form igneous rocks (Stofflett, 1993)
Weather forms igneous and metamorphic rocks (form in dry environments), particularly changing weather (Stofflett, 1994)
Igneous and sedimentary rocks form because of pressure (Stofflett, 1994)
Igneous and metamorphic rocks form by the crushing and compacting of smaller debris with time (Stofflett, 1994)
Sedimentary rocks
Oolitic limestone is sandstone because of its crumbly texture (Dove, 1996) (31%)
Coal is the same as charcoal (Dove, 1996) (14%)
Pebbles grow, clumping at the bottom of rivers (Kusnick, 2002)
Rounded pebbles found in sedimentary rocks must be sedimentary (Kusnick, 2002)
Heat and pressure is a prerequisite to sedimentary rock formation (Stofflett, 1993)
Rocks are formed where they are found; if in a river they must be sedimentary (Kusnick, 2002)
Igneous and sedimentary rocks form because of pressure (Stofflett, 1994)
Igneous and metamorphic rocks form by the crushing and compacting of smaller debris with time (Stofflett, 1994)
Coal is not a rock because it is an energy source (Dove, 1996)
Metamorphic rocks
Weather forms igneous and metamorphic rocks (form in dry environments), particularly changing weather (Stofflett, 1994)
Foliation is due to layering by depositional processes (Stofflett, 1994)
Slate is not a rock because it is only a building stone (Dove, 1996)
Group or age category: college (n = 6)
General characteristics
Rocks (and minerals) grow (Kirby, 2011) W
Slate, marble, and coal are materials (useful in building, cemeteries, and energy) rather than rocks (Dove, 1996)
Minerals
With minerals, the term 'massive' texture means that the samples are big (Kirby, 2011) W
Igneous rocks
Coarse-grained rocks are rough, fine-grained rocks are smooth (Kirby, 2011) W
Sedimentary rocks
Separations along bedding plane, like those that dominate most sedimentary outcrops, occur deep beneath the Earth's surface (Kirby, 2011) W

(*Continued*)

Table 9. Continued

Coarse-grained sedimentary rocks cooled slowly, coarse-grained igneous rocks formed in areas of high depositional energy, etc. (Kirby, 2011) W
Group or age category: high school (n = 9)
General characteristics
Rocks and minerals are synonymous (King, 2010) (2% out of 531 errors or simplifications found in textbooks from England and Wales)
Rock cycle
The rock cycle is steady and continuous (King, 2008)
The rock cycle takes millions of years to occur (King, 2008)
Igneous rocks
Basalt and granite form from the same magmas (King, 2008, 2010) (2% out of 531 errors or simplifications found in textbooks from England and Wales)
Sedimentary rocks
Sedimentary rocks formed by compression only (King, 2010) (4% out of 531 errors or simplifications found in textbooks from England and Wales)
If a rock contains fossils it has to be sedimentary (fossils can be preserved with low-grade metamorphism) (King, 2008)
The weight of the ocean causes sedimentary rocks to form (King, 2008)
Metamorphic rocks
Metamorphism only caused by overburden pressure (King, 2010) (2% out of 531 errors or simplifications found in textbooks from England and Wales)
Group or age category: middle school (n = 9)
General characteristics
Only one process is involved in rock formation (60%) (Ford, 2003)
Rocks are defined on the basis of physical properties like hardness or shape (23%) (Ford, 2003)
All rocks are heavy (Phillips, 1991)
Rock cycle
Only igneous and sedimentary rocks go through the rock cycle (Ford, 2003)
Each part of the rock cycle is stagnant and isolated and cannot change or be transformed into any other part of the rock cycle system (Kali et al., 2003)
The internal and external processes of the rock cycle are not related or connected (Kali et al., 2003)
Once material reaches the surface it cannot return to the interior of the Earth (Kali et al., 2003)
Rock cycle is the cause of rock formation rather than a model showing relationships between rock categories and rock genesis (Ford, 2003)
Group or age category: middle/high school (n = 1)
General characteristics
Rocks are always solid (AAAS Project 2061, n.d.) (36%) (32%)
Group or age category: primary (n = 5)
General characteristics
Shape used to identify rocks (Ford, 2005) (11%)
Hardness used to identify rocks (Ford, 2005) (5%)
All rocks come from volcanoes, water, moon, from ocean migrating up streams (Ault, 1982)
All rocks are heavy (Happs, 1982)
Rocks are created by God, humans building houses, or grew from seeds (Piaget, 1929)

wind, and to a lesser extent, liquid and solid water as active weathering process. This is perhaps understandable given that moving water, while acting as an agent of erosion, dislodging sediments, can also break down rock *in situ* through solution. There was

Table 10. Soil misconceptions (13 misconceptions)

Group or age category: undefined (n = 3)
Origin
  Soil derives from rivers, volcanoes, or was here since the earth formed (Hapkiewicz, 1999)
  Soil comes from rivers (Hapkiewicz, 1999)
  Soil originates from volcanic action (Hapkiewicz, 1999)
Group or age category: high school (n = 3)
Origin
  Soils are old, from a million years to the formation of the earth (Happs, 1984)
  Soils change into clays and then rocks as a result of increasing pressure
Thickness
  Soil depth extends from a few meters all the way to the center of the earth (Happs, 1984)
Group or age category: middle school (n = 1)
Origin
  Soil has always existed in its present form (Phillips, 1991)
Group or age category: primary (n = 6)
Origin
  Soil was formed when the earth formed (Russel, Bell, Longden, & McGuigan, 1993, cited by Dove, 1998)
  Soil is unchanging (Russel et al., 1993, cited by Dove, 1998)
Composition
  Soil is brown and homogeneous (Russel et al., 1993, cited by Dove, 1998)
  Soil does not contain air (Russel et al., 1993, cited by Dove, 1998)
  Twigs, mold, and stones are found in rock but are not an integral part of it (Russel et al., 1993, cited by Dove, 1998)
Thickness
  Soil can extend for several miles underneath the earth's surface (Russel et al., 1993, cited by Dove, 1998)

Topic	Undefined	In-service teachers	Pre-service teachers	College	High school	Middle school	Middle/high school	Primary
Earth structure		6		12	3	5	1	5
Geologic resources					4		4	21
Glaciers	5			10	1		2	
Historical geology	25	4	9	15	3	8	1	2
Karst	8			1				
Plate tectonics		3		21			67	2
Rivers			1	8			10	11
Rocks and minerals			26	6	9	9	1	5
Soils	3				3	1		6
Volcanoes	7	3	1	17	2			7
Weathering and erosion	2		1				64	1

Figure 3. Number of misconceptions by topic and assigned to different groups/age categories

also a failure to connect current weathering products in the form of smaller pebbles to the parent material from which it derived. Although not mentioned specifically, soils would likely be thought of as unrelated to weathering of parent material.

Table 11. Volcano misconceptions (37 misconceptions)

Group or age category: undefined (n = 7) ('W' indicates web source where peer review process is not clearly stated)

Form and Eruption style

- All volcanoes erupt violently (Fries-Gaither, 2008) W
- If a volcano does not produce lava, it is not dangerous (Fries-Gaither, 2008) W
- Volcanoes only erupt straight up through the top vent (Fries-Gaither, 2008) W
- If a volcano does not erupt for a hundred years, it is extinct (Fries-Gaither, 2008) W

Distribution

- Volcanoes are randomly located across the earth's surface (Fries-Gaither, 2008) W
- Volcanoes are found only on land (Fries-Gaither, 2008) W
- Volcanoes are found only in hot climates (Fries-Gaither, 2008) W

Group or age category: in-service teachers (n = 3)

Origin

- Magma supply for volcanoes comes from inner core (Dahl et al., 2005)

Distribution

- Could not differentiate volcano distribution as a function of plate melt and mantle plume origin (King, 2000) (9%)
- Volcanoes are typically warm climate features (Dahl et al., 2005) (9%)

Group or age category: pre-service teachers (n = 1)

Distribution

- Volcanoes are typically warm climate features (Dahl et al., 2005) (26%)

Group or age category: college (n = 17)

Origin

- Wind blowing across the tops of volcanic mountains can cause eruption, similar to wind blowing over opening of a flute (Kirby, 2011) W
- Basalt's origin is connected to the presence of seawater (Kirby, 2011) W
- Magma comes from molten layer beneath Earth's crust (Kirby, 2011) W
- Magma comes from deep within Earth's mantle (Kirby, 2011) W
- Magma comes from Earth's outer core (Kirby, 2011) W
- Most magma forms as rock is subjected to great pressure deep within the Earth (Kirby, 2011) W

Form and Eruption style

- Volcanic eruptions are rare events (Kirby, 2011) W
- Most deaths during volcanic eruptions are due to suffocation from smoke or poisonous gases as opposed to secondary causes like famine, tsunami's and lahars (Kirby, 2011) W
- Most deaths during volcanic eruptions are due to fear and panic during evacuation (Kirby, 2011) W
- Most volcanoes are tall peaks with craters at summit (Kirby, 2011) W
- Volcanoes are only hazards, not important long-term resources (Kirby, 2011) W

Distribution

- Volcanoes only form near bodies of water (Boudreaux et al., 2009)
- Volcanoes are common only in areas near the equator or other warm areas (Boudreaux et al., 2009)
- Volcanoes are dominantly tropical features (Kirby, 2011) W
- Volcanoes appear in areas of rocky terrain (Boudreaux et al., 2009)
- There is no pattern to volcano formation (Boudreaux et al., 2009)
- Volcanoes only occur on islands in warm equatorial climates (Libarkin & Anderson, 2005)

Group or age category: high school (n = 2)

(*Continued*)

Table 11. Continued

Volcanoes result when magma is squeezed up through the crust (as opposed to magma's lower density being the driving force upward) (King, 2008)
All volcanoes produce lava when erupting (as opposed to explosions, ash, and bombs) (King, 2008)
Group or age category: primary (n = 7)
Origin
Heat-related mechanism(s) only: No movement-related mechanism (Gobert, 2005)
Movement-related mechanism(s) only; no heat as causal agent in movement of plates (Gobert, 2005)
Volcanoes are created by mountains, the sun, or the earth's mood (Ross & Schuell, 1993)
Lava's heat comes from the sun (Sharp et al., 1995)
Lava originates from the core (Sharp et al., 1995)
Form and Eruption Style
Volcanoes don't have snow on them (Dove, 1998)
Distribution
Volcanoes are not found in cold climates (Dove, 1998)

Directions for Future Research

Figure 3 shows the number of misconceptions by topic and assigned to different groups/age categories. As can be seen in Figure 3, misconception research, involving glaciers, geologic resources, karst and soils, is lacking. Misconception data exist for most other subjects at the middle-school/high-school levels. There is also adequate coverage at the primary and college levels, but there is a lack of information on the extent of misconceptions for pre- and in-service teachers. In the latter case, a possible roadblock to future studies with in-service teachers might be their hesitancy to participate in such studies for fear of retribution in the event that their subject matter inadequacy is discovered. In-service teachers, thus, need to be assured of complete anonymity if they participate in a misconception study. In-service teachers, on the other hand, are probably easier to access and would appear to be a promising sampling group for future studies.

This study suggests that misconceptions do exist for various groups and age levels, but only a few authors attempt to remediate the misconceptions they discovered. Gobert and Clement (1999) demonstrated the benefit of student-generated diagrams as opposed to reading student-created summaries when correctly portraying the earth layers, continental movement, volcanic eruptions and mountain formation. Steer, Knight, Owens, and McConnell (2005) corrected misconceptions regarding earth structure with drawings and cooperative group activities. These types of studies, demonstrating the existence of misconceptions *and* providing guidance on how to remediate misconceptions, are to be encouraged. One specific area of worthwhile research would be to gauge the effect of field work and field observations on reducing misconceptions. Many of the concepts associated with weathering/erosion, such as jointing, sand, rain and frost, can be observed on many campuses, even the most

Table 12. Weathering and erosion (68 misconceptions)

Group or age category: undefined (n = 2)
Chemical weathering
Mineral weathering susceptibility is solely a function of the crystallization temperature and pressure differences between environments of formation (Wampler, 1997)
The weathering of New York City's granitic Cleopatra's Needle is cited as an example of the impact of the wet, polluted atmosphere of New York (Wampler, 1996)
Group or age category: pre-service teachers (n = 1)
General characteristics
Weathering is due to earthquakes and volcanic eruptions (Kusnick, 2002)
Group or age category: middle/high school (n = 64) (first number in parentheses is from the middle-school sample, the second, from the high school sample)
General characteristics
Weathering and erosion are synonymous (King, 2010) (7% out of 531 errors or simplifications found in textbooks from England and Wales)
Weather causes weathering (King, 2008)
Erosion takes place over millions of years (King, 2008)
Weathering is solely caused by atmospheric phenomenon (Dove, 1997)
Erosion occurs all the time while weathering is intermittent (Dove, 1997)
Erosion wears down the surface while weathering breaks up the surface (Dove, 1997)
Weathering cannot be prevented but erosion can (Dove, 1997)
Rain splash is weathering (Dove, 1997)
Weathering is always a precursor to erosion (Dove, 1997)
All erosional processes are physical (not chemical) (Dove, 1997)
All weathering processes are chemical (Dove, 1997)
Wind and rain are weathering processes because weather is involved (Dove, 1997)
The small loose rocks on the surface of the earth were never part of the solid rock layer (AAAS Project 2061, n.d.) (50%) (45%)
The large loose rocks on the surface of the earth were never part of the solid rock layer (AAAS Project 2061, n.d.) (49%) (46%)
Very large rocks the size of boulders do not come from breaking off from earth's solid rock layer (AAAS Project 2061, n.d.) (45%) (40%)
Rocks cannot break by colliding with other rocks (AAAS Project 2061, n.d.) (27%) (21%)
Very large rocks the size of boulders do not come from breaking off from larger rocks (AAAS Project 2061, n.d.) (27%) (23%)
The rock material of sand was never part of earth's solid rock layer (AAAS Project 2061, n.d.) (25%) (22%)
Wind and water only change the surface of the earth during rare events, such as huge storms (AAAS Project 2061, n.d.) (20%) (20%)
Large rocks (such as boulders) have always been loose rocks. They were never part of earth's solid rock layer (AAAS Project 2061, n.d.) (21%) (19%)
It only takes hundreds of years for wind and water to wear away the solid rock of a mountain (bedrock) so that the mountain is almost flat (AAAS Project 2061, n.d.) (18%) (18%)
Wind and water cannot wear away solid rock to make a valley deeper or wider (AAAS Project 2061, n.d.) (15%)
Wind and water cannot wear away the solid rock of a mountain (AAAS Project 2061, n.d.) (15%) (13%)
Liquid water cannot break rock (AAAS Project 2061, n.d.) (10%) (11%)

(*Continued*)

Table 12. Continued

Erosion can wear away solid rock a little bit but could never have a big effect on the surface of the earth such as leveling mountains or carving valleys (AAAS Project 2061, n.d.) (11%) (11%)
Wind and water cannot wear away the solid rock of a mountain (AAAS Project 2061, n.d.) (14%) (11%)
Landforms look similar today as they did many millions of years ago. For example, a river on earth today has not changed over time (Dove, 1998; Trend, 1998) (11%)
Wind and water cannot wear away the solid rock of a mountain (AAAS Project 2061, n.d.) (11%)
Landforms can change in size, but not by the motion of wind and water (AAAS Project 2061, n.d.) (10%)
Rain cannot wear away solid rock (AAAS Project 2061, n.d.) (9%) (9%)
Landforms can change in size, but not by the motion of wind and water (AAAS Project 2061, n.d.) (11%) (9%)
Water cannot wear away solid rock (AAAS Project 2061, n.d.) (9%) (8%)
No loose rock material on the surface of the earth was ever part of the earth's solid rock layer (AAAS Project 2061, n.d.) (8%) (7%)
Water cannot wear away solid rock (AAAS Project 2061, n.d.) (7%) (7%)
Time scale for weathering and erosion
Weathering is slower than erosion (Dove, 1997)
Water can wear away only a small amount of a mountain's height (feet or inches) over millions of years (AAAS Project 2061, n.d.) (55%) (53%)
It takes rain a long time to wear away solid rock, even very small amounts that you cannot see (AAAS Project 2061, n.d.) (54%) (53%)
Wind and water are changing the surface of the earth today but did not change the surface of the earth in the past (AAAS Project 2061, n.d.) (13%)
Wind and water changed the surface of the earth in the past but are no longer changing the surface of the earth (AAAS Project 2061, n.d.) (16%) (12%)
It takes only a short time (tens of years) for wind and water to wear down the solid rock of a mountain so that the mountain is almost flat (AAAS Project 2061, n.d.) (11%) (8%)
Very large rocks, such as boulders, have always been the way they are today (AAAS Project 2061, n.d.) (10%) (10%)
Landforms look similar today as they did many millions of years ago. For example, a river on earth today has not changed over time (Dove, 1998; Trend, 1998) (8%) (9%)
Physical weathering
Rocks are weathered only by freezing (expansion) of ice (King, 2010) (2% out of 531 errors or simplifications found in text books from England and Wales)
Water that freezes in cracks in rock cannot break the rock (AAAS Project 2061, n.d.) (15%) (13%)
Chemical weathering
Water cannot deposit dissolved rock as solid rock (AAAS Project 2061, n.d.) (31%) (31%)
Water cannot dissolve rocks (AAAS Project 2061, n.d.) (24%)
Biotic weathering
The growth of plant roots cannot break rock (AAAS Project 2061, n.d.) (45%) (38%)
Wind erosion
Sandblasting is weathering (Dove, 1997)
Wind can wear away the solid rock of mountains only a small amount (feet or inches) over millions of years, not thousands of feet (AAAS Project 2061, n.d.) (55%) (55%)
Wind can make a valley deeper by only a small amount (feet or inches) over millions of years (AAAS Project 2061, n.d.) (55%) (55%)

(*Continued*)

Table 12. Continued

Wind can only wear down solid rock over long time periods. Changes are not happening over short time periods (i.e. a day or a year) (AAAS Project 2061, n.d.) (50%) (48%)
Wind cannot break grains of sand (AAAS Project 2061, n.d.) (41%) (45%)
Wind cannot break rock (AAAS Project 2061, n.d.) (41%) (41%)
Wind cannot break solid rock (AAAS Project 2061, n.d.) (33%) (35%)
Wind can carry small rocks (e.g. sand) but never carries large rocks (e.g. fist-sized) (AAAS Project 2061, n.d.) (37%) (34%)
Wind cannot carry rock and deposit it in a new location (AAAS Project 2061, n.d.) (31%) (31%)
Wind is wearing away the solid rock of valleys today but did not wear away the solid rock of valleys in the past (AAAS Project 2061, n.d.) (27%) (21%)
Wind and water cannot wear away solid rock to change the shape of a coastline (AAAS Project 2061, n.d.) (23%) (19%)
Wind wore away the solid rock of valleys in the past but is not wearing away the solid rock of valleys today (AAAS Project 2061, n.d.) (25%) (20%)
Ocean waves cannot wear away the solid rock of a cliff over time (AAAS Project 2061, n.d.) (16%) (18%)
Wind cannot move grains of sand (AAAS Project 2061, n.d.) (18%) (16%)
Solid rock was being worn away by wind many years ago, but it is no longer being worn away by wind today (AAAS Project 2061, n.d.) (16%) (16%)
Solid rock is currently being worn away by wind, but it was not being worn away by wind many years ago (AAAS Project 2061, n.d.) (13%) (13%)
Wind cannot wear away solid rock (AAAS Project 2061, n.d.) (9%) (10%)
Group or age category: primary (n = 1)
General characteristics
Stones are round because the stones are made that way (Piaget, 1929)

urban. Such backyard field trips could be a good place to start for addressing misconceptions.

Conclusion

It was the intention of this review to provide teachers, curriculum developers and researchers with an organized, easy to access resource to address geoscience misconceptions. Plate tectonics and erosion/weathering were topics that had the most misconception coverage, especially at the high-school and middle-school levels. The supernatural origin for many of the geoscience phenomena listed here is abandoned in most cases by middle school but in other cases, some misconceptions seem robust through adulthood. Some, like humans and dinosaurs co-existing, are infused throughout popular culture and never quite disappear. Other misconceptions require strong content knowledge that is often lacking in students, like the idea that basalt and granite can derive from the same melt. Persistent misconceptions highlighted in this study involve the origin of earthquakes, thickness of the earth's crust, oil's origin, movement mechanisms for glaciers, co-existence of humans and dinosaurs, water movement within karst terrains, the nature of plate boundaries, the power of water as an agent of geomorphic change, what constitutes a mineral and a rock, thickness of the soil layer, the distribution of volcanoes, and the difference between weathering and erosion.

More research is needed with pre- and in-service teachers. With regard to subject area, more research should be devoted to soils' misconceptions. Soil stewardship is vital to the future of the planet's food production, but has had relatively little research. Karst terrains occupy up to 15% of land, yet little has been written on this topic.

There are real obstacles to overcome the persistence of misconceptions, ranging from inadequate prerequisite knowledge and overlapping concepts to the oversimplification of geoscience topics as portrayed in Hollywood movies. The good news is that few misconceptions had over 50% of a sample population adhering to a particular age appropriate misconception. It is also comforting to know that misconceptions can be remediated through diagramming, concept mapping, remedial text and other active learning techniques.

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