

AN ANALYSIS OF MISCONCEPTIONS IN SCIENCE TEXTBOOKS: EARTH SCIENCE IN ENGLAND AND WALES

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| EARTH SCIENCE IN E | NGLAND AND WALES | |
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| Running heading: Misconceptions in scien | ce textbooks: earth science | |
| ABST | RACT | |
| Surveys of the earth science content of | all secondary (high school) science | |
| textbooks and related publications used | in England and Wales have revealed | |
| high levels of error/ misconception. The | | |
| series surveyed (51 texts in all) showed | | |
| earth science and contained a mean lev | | |
| misconception per page. Science syllab | uses and examinations surveyed also | |
| showed errors/ misconceptions. | | |
| More than 500 instances of missensenti | on wore identified through the | |
| More than 500 instances of misconcepti | 5 | |
| surveys. These were analysed for freque earth science curriculum most prone to | | |
| processes/ rocks, earthquakes/ Earth's | | |
| processes/ rocks, earlinguakes/ Larins | structure, and plate tectoriles. | |
| For the fifteen most frequent misconcep | tions examples of quotes from the | |
| textbooks are given, together with the so | | |
| and an example of a misconception of s | | |
| science. | | |
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| The misconceptions identified in the sur | veys are compared with those | |
| described in the literature. This indicates | s that the misconceptions found in | |
| college students and pre-service/ practis | | |
| found in published materials, and theref | | Deleted: . These materials |
| misconceptions in teachers and their stu | | Deleted: , often in key areas of the |
| the prevalence earth science misconcer | <u>otions in the UK secondary (high</u> | earth science curriculum |
| school) science teaching population. | | |
| The analysis and discussion provides th | e opportunity for writers of secondary | Deleted: is information |
| science materials to improve their work | | |
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EARTH SCIENCE IN ENGLAND AND WALES

'Earth science' in the National Curriculum for Science (NCS) in England and Wales covers content that is largely geology-related and so differs from the broader 'earth science' taught through some science curricula in other parts of the world. The 'earth science' in the NCS evolved through four mandatory versions prior to the survey reported below, as described in King (2001). The initial version (DES, 1989) contained 17 sections of content including two directly related to earth science, namely 'Human influences on the Earth' and 'Earth and atmosphere'. During subsequent revisions, the 'Human influences on the Earth' section was incorporated into biological sections, and developed a strong ecological flavour. Meanwhile, the 'atmosphere' section was largely removed and the 'earth' section, comprising largely geological material, was incorporated in the chemical section.

The textbook survey was carried out against the version of the National Science Curriculum based on this model, that was mandatory at the time (QCA, 1999). For 11-14 year olds (Key Stage 3, KS3) this involved: physical and chemical weathering; the formation of sedimentary, igneous and metamorphic rocks; a discussion of different energy sources; and a little on environmental protection. Meanwhile, 14-16 year olds (Key Stage 4, KS4) covered: fossils in the context of evolution; environmental issues; changes in the atmosphere and ocean over time and the carbon cycle; evidence for sedimentary, igneous and metamorphic rock formation and their subsequent deformation; seismological evidence for the Earth's structure; plate tectonics; and the radioactive dating of rocks.

Since the textbook survey was carried out, the National Curriculum for Science has been revised yet again, the section for 14-16 year olds (KS4) in 2004 (DES, 2004) and the section for 11-14 year olds in 2007 (QCA website). In these revisions, the content of the curriculum is presented in a less detailed and prescriptive way, but the earth science has been separated out into a separate section again, separated from the biological, chemical and physics content.

In other countries across the globe, 'earth science' often includes much more on the atmosphere and oceans and on environmental change than is covered by the science curriculum in England and Wales (King, 2008a). In England and Wales, this material is usually covered in more detail in the geography curriculum.

Thus, the perspective on 'earth science' taken as the basis for this research is the geology-centred earth science studied in secondary (high) schools in England and Wales.

TEXTBOOKS, SYLLABUSES AND EXAMINATIONS IN ENGLAND AND WALES

A survey of all the science textbooks in print and being used in secondary (high) schools in England and Wales was carried out in the Spring of 2002. All the major publishers of science textbooks who exhibited at the Association for Science Education (ASE) Annual Meeting in January 2000, and all the relevant textbooks in print that they published, were covered by the survey. Each contributed between one and five textbooks or series. A total of 13 books or series for 11-14 year old pupils (KS3) was reviewed and 16 books or series for 14-16 year olds (KS4). The total

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number of individual books surveyed was 27 at KS3 and 24 at KS4, a grand total of 51 books. The full survey was described in a report (King et al, 2002) and in a subsequent publication (King et al, 2005).

The 'errors/ oversimplifications' identified in the textbook survey were added to the similar list derived from a previous survey of syllabuses and examinations for 16 year olds (King et al, report 1998, publication 1999). Since publication of the textbook report, other sources of earth science information written for 11 – 16 year olds were, examined and some publishers, invited the authors of the reports to proof-read drafts of textbook material. During these exercises, more examples of 'error/ oversimplification' were identified and added to the list. The final list of 'error/ oversimplification' examples recorded through all these surveys numbered more than 500.

In the England and Wales, government control of the content of school science is restricted to publication of the National Curriculum for Science, such as the current example (QCA website), and oversight of the examination processes. This provides freedom for any publisher to produce textbooks or other teaching materials without government scrutiny. Meanwhile the examination processes are managed by commercial organisations called Awarding Bodies (or Exam Boards). The Awarding Bodies produce the syllabuses, which should cover the National Curriculum content, and a government body, the Qualifications and Assessment Authority, approves the syllabuses. The Awarding Bodies produce the examinations to assess each syllabus.

As a result of the freedom available to publishers and Awarding Bodies, a range of different publications and syllabuses (with associated examinations) has become available. However, there is little detailed scrutiny of content, particularly in areas less familiar to many teachers and writers, such as earth science. The result is the wide range of 'errors/_oversimplifications' in textbooks, syllabuses and examinations identified in the surveys.

The scale of this issue in the UK was highlighted recently by a piece on earth science submitted for inclusion on the website of a learned scientific institution. Proof reading found ten 'errors/ oversimplifications' in 328 words (King, 2008b), an average of one error in every 33 words.

The 'errors' oversimplifications' from the textbook and syllabus/examination surveys have been collated to provide insight into the misunderstandings prevalent in the writers of these materials. These are likely to be indicative of the misconceptions held by many science teachers. The misconceptions are being promulgated through use of the textbooks, syllabuses and examinations that are prone to error.

SCIENCE TEXTBOOKS AND THEIR IMPORTANCE

A review carried out in the late 1990s amongst nearly 150 science teachers teaching earth science in England and Wales (King_ 2001) showed that their own educational backgrounds in earth science was poor and that science textbooks were key sources of information for them. These included science textbooks written for 11–14 year olds (25% of responses), science texts written for 14–16 year olds (15%) and general science textbooks (29% of respondents). Science textbooks were much

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More than 500 instances of earth science 'errors/ oversimplifications' have been recorded through surveys of materials published for secondary science teaching in England and Wales.

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more widely used than earth science-specific materials (used by a mean of only 12% of respondents). The only more widely used source of support was their science colleagues (46% of respondents).

This research indicating widespread use of textbooks in the UK is supported by a report of the government Council for Science and Technology (CST, 2000) which found that 89% of the 586 secondary (high) school teachers surveyed used science textbooks 'often' (whilst 39% used their colleagues 'often' as well).

Meanwhile Ball and Cohen (1996), quoting Goodlad (1984), note that 'Commercially published curriculum materials dominate teaching practice in the United States', and continue,

Unlike frameworks, objectives, assessments and other mechanisms that seek to guide curriculum, instructional materials are concrete and daily. They are the stuff of lessons and units, of what teachers and students do. That centrality affords curricular materials a uniquely intimate connection to teaching' (p6).

It was for this reason that the American Association for the Advancement of Science, as part of its Project 2061, undertook a review of science textbooks available to teachers in the USA. Their findings have been reported and discussed in a number of reports and publications. In one of these, Kesidou & Roseman, (2002) state that, Whereas curriculum materials (and in particular textbooks and their accompanying teacher's guides) are but one of the resources available to teachers, they have a major role in teaching and learning. Many teachers rely on them to provide some or all of their content and pedagogical knowledge, and this is specially so when the teacher is a novice or is teaching outside his or her area of expertise ...' (p522).

Stern & Roseman (2004) add, 'For better or for worse, the majority of schools are still relying on textbooks as the primary source of the classroom curriculum, and textbooks strongly influence student learning through their influence on teachers.' (p556).

The overall findings of the Project 2061 textbook evaluation team were that the textbooks evaluated were generally poor in a number of ways. For example, 'Programs [textbook teaching schemes] only rarely provided students with a sense of purpose for the units of study, took account of student beliefs that

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| Deleted: Then Renner et al. (1990) quote Harmes & Yager (1981) as, 'Research has shown that over 90 percent of all science teachers use a textbook 95 percent of the time' (p35). |
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interfere with learning, engaged students with relevant criteria to make abstract scientific ideas plausible, modelled the use of scientific knowledge so that students could apply what they had learned in everyday situations, or scaffolded student efforts to make meaning of key phenomena and ideas presented in the programs.' (Kesidou & Roseman, 2002, p522),

'currently available curriculum materials provide little support for the attainment of key ideas chosen by this study. In general, these materials do not take into account students' prior knowledge, lack representations to clarify abstract ideas, and are deficient in phenomena that can be explained by the key ideas and hence make them plausible.' (Stern & Roseman 2004, p538), and

'Assessment scores of life and earth sciences are almost uniformly poor' (Stern & Ahlgren, 2002, p897).

Although the research methodology of the Project 2061 researchers has been questioned (Holliday, 2003), it has also been strongly defended (Kesidou & Roseman, 2003).

As part of their work, the Project 2061 evaluation team reviewed the earth science content of middle school science textbooks (for 11 – 14 year olds) published in the USA against eight earth science ideas. Their ratings, as published on the Project 2061 website (AAAS – Project 2061), find the texts examined to be almost universally poor when measured against a range of instructional categories.

This issue is prevalent in other educational systems, as indicated by Sellés-Martinez (2007) for Argentina, in citing examples of the earth science content of seven Spanish introductory science textbooks which, 'rendered alarming results.' (p207).

This review of importance and quality of science textbooks, and particularly their earth science components, provides the backdrop to the surveys carried out in England and Wales.

SURVEY METHODOLOGY THAT IDENTIFIED ERRORS AND OVERSIMPLIFICATIONS

'Errors/_oversimplifications' were first identified in a survey of the GCSE science examination syllabuses in use in England and Wales in 1996. General Certification in Secondary Education (GCSE) syllabuses and examinations are aimed at 16 year
olds, which are taken by more than 80% of the school students in the two_countries. The survey was undertaken by five experienced earth science teachers and examiners and covered all 11 examinations available in 1996 in England and Wales at the time. The survey covered the syllabuses used and the science examinations set for each of the syllabuses in 1996. Each syllabus and set of examination papers was evaluated independently against a proforma by two members of the working group and their views were combined by a moderator to provide an overview. The findings were reported in King et al. (report 1998, publication 1999). The survey identified poor coverage of the earth science components of the National Curriculum and no syllabuses that were error-free; 13 'errors/ oversimplifications' were recorded.

Meanwhile the examinations showed a preponderance of low level, recall-based

questions and <u>also_contained errors</u>. Three of the eleven sets of papers contained seven 'errors/_oversimplifications' between them. The draft survey report was sent to all the Awarding Bodies for comment. No feedback was received and so the final report was prepared and widely circulated.

It is noteworthy that a more recent survey of the six <u>GCSE</u> science syllabuses available in England and Wales in 2004 (King et al. 2004) found better National Curriculum coverage and a much reduced 'error/ oversimplification' level. The most recent 2007 survey of the five GCSE science <u>syllabuses (now called specifications)</u> currently used, found a poorer National Curriculum coverage but a further reduction in the level of 'error/ oversimplification' (King and Hughes, <u>report 2007, publication</u> 2008). The reduction in the level of 'error/ oversimplification' over time may reflect publication and dissemination of the results of the previous surveys.

A survey of all the science textbooks in print and in use in schools in England and Wales was undertaken in 2002 to identify a base level of quality of earth science content against which future textbooks could be judged (King et al, report 2002, publication 2005). As indicated above, 13 books or series (programs) for 11–14 year old pupils and 16 books or series for 14–16 year olds were reviewed, involving 27 books for the 11-14 age range and 24 for 14-16 year olds, a total of 51 textbooks.

The survey was carried out by four experienced earth science educators. Initially a proforma similar to that used in the syllabus survey above was agreed, through which each book could be checked for National Curriculum coverage, and percentage of earth science content and any 'errors/_oversimplifications' included would be noted. The recorded 'errors/ oversimplifications' were not simply typing or grammatical errors, but were errors which showed that the author had an incorrect understanding of the process being described. The 'oversimplifications' involved simplifications that had introduced errors. All of the 'errors/ oversimplifications' recorded were re-written correctly at a similar language level and with a similar number of words, to illustrate to the publishers and authors that the material could have been presented correctly.

The proforma was initially applied by all the reviewers to the same textbook and, following discussion at the moderation meeting, the final form of the proforma and methodology was agreed. Each reviewer then reviewed their quota of textbooks and their results were moderated by the coordinator. The complete set of moderated comments was circulated to all involved for further comment and checking before the results were collated. The findings allowed the textbooks to be ranked in terms of National Curriculum coverage, amount of earth science included (percentage of pages of earth science relative to the number of pages of the book), numbers of 'errors/ oversimplifications' and amount of material additional to the National Curriculum content.

Finally, the full 100+ page draft report containing all the data was sent to all the publishers involved for their response, and the limited feedback received was incorporated, before publication and wide circulation of the final report. The report findings are summarised in Table 1.

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| 2 | Table 4 however Decelies date abtained from the company of the conthe science | |
| 3 | Table 1 hereabouts. Baseline data obtained from the survey of the earth science | Formatted: Fo |
| 4 | content of secondary science textbooks, Spring 2002. | |
| 5 | | |
| | The report findings show that that more than half the National Curriculum earth | |
| 6 | science content was inadequately covered and that the mean level of 'error/ | |
| 7 | oversimplification' was one error per page of earth science. Of the 29 textbooks/ | |
| 8 | series evaluated (several textbooks in the same series were treated together), no | |
| 9 | textbook/series was completely error-free. The lowest error level was 0.1 error per | |
| 10 | page of earth science. Seventeen textbooks/series had 0-1 errors per page; nine | Deleted: 17 |
| 11 | textbooks/series had 1-2 errors per page and three textbooks/series had more than | Deleted: 9 |
| 12 | two errors per page, the worst having 2.5 errors per page (66 'errors/ | Deleted: 3 |
| 13 | oversimplifications' in 26 pages). Through the textbook survey, 453 instances of | |
| 14 | 'error/ oversimplification' in total were recorded. | |
| 15 | | |
| 16 | During 2003, more instances of 'error/oversimplification' in material published for | |
| 17 | use by science teachers were identified: 38 from proof-reading of pre-publication | |
| 18 | science textbook material and 20 from a BBC science revision website. | |
| 19 | | |
| 20 | Together a total of 531 instances of 'error/ oversimplification' was identified from all | Deleted: was |
| 21 | these sources, and these form the basis of the analysis undertaken below. | |
| 22 | | |
| 23 | EARTH SCIENCE 'ERROR/ OVERSIMPLIFICATION' DATA COLLECTED FROM | |
| 24 | THE SCIENCE-TEACHING MATERIALS | Formatted: Fo |
| 25 | The 531 instances of 'error/oversimplification' have been categorised and are shown | `` |
| 26 | graphically in Figure 1. | Formatted: Fo |
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| | Figure 1 hereabouts. Instances of earth science 'error/ oversimplification' in | |
| 28 | published science materials for $11 - 16$ year olds in England and Wales (n = 531). | |
| 29 | published science materials for TT – To year olds in England and Wales (T – 53T). | |
| 30 | Figure 4 is directed that the market it of the set of the BC at the set of th | |
| 31 | Figure 1 indicates that the majority of 'errors/_oversimplifications' relate to rocks and | |
| 32 | rock-forming processes (40%), particularly to sedimentary rocks and processes | |
| 33 | (24%). A high percentage is found in the earthquake, Earth's structure and plate | |
| 34 | tectonic categories (29%), whilst in the data relating to economic geology, more than | |
| 35 | half (9% of the total) related to energy. | |
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| 37 | Some 'errors/_oversimplifications' occurred in the data as multiple instances and | |
| 38 | these have been ranked in order to show those 'errors/_oversimplifications' that are | |
| 39 | most widespread amongst writers of published science materials. The 'top 15' | |
| 40 | examples of 'error/ oversimplification' found are ranked in Table 2, each instance | |
| 41 | comprising more than 1.3% of the data. The table lists: | |
| 42 | the earth science 'error/_oversimplification' as it might be found in a textbook; | |
| 43 | its prevalence in the data; | |
| 44 | examples of quotes containing 'errors/ oversimplifications' taken from the | |
| 45 | materials reviewed | |
| 46 | the scientific consensus view, given as quotes from authoritative textbooks; | |
| 40 | discussion – providing guidance to those attempting to address the 'error/ | |
| 47 | oversimplification' in question; | |
| 40 49 | an example of an 'error/ oversimplification' of similar significance in another | |
| | | |
| 50 | science area – provided to give some indication to the non-specialist of the | |
| 51 | 'importance' of the 'error/ oversimplification' to the teaching of earth science. | |
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| (11 – 16 year old) science textbooks in England and Wales – in rank order of frequency. | |
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| ERRORS/OVERSIMPLIFICATIONS, MISCONCEPTIONS AND ALTERNATIVE CONCEPTIONS The term 'errors/ oversimplifications' has been used above because of its usage in the two reports King et al. (1998) and King et al. (2002). The term was used independently of any usage of the terms in research literature, specifically for use with sources of information written for teachers and pupils (pupil textbooks, examination syllabuses, etc). | Deleted: ¶ ¶ ¶ |
| However there has been wide discussion in the literature around the best terminology to use for instances of error and misconception. For example Abimbola, (1988) cites the following usage, 'the kinds of knowledge that researchers consider as 'wrong' knowledge [include the following examples] 'errorneous (sic) concepts' ; 'misconceptions' ; 'misunderstandings' ; 'errorneous ideas'; and 'mistakes'' (p178). | Deleted: like these |
| He goes on to discuss use of the terms 'alternative frameworks' and 'alternative conceptions'. 'Alternative conceptions' is his preferred term, for, 'particular conceptions that are held strongly and persistently by students' (p180). | |
| Wandershee et al, (1994) in their discussion of the 'plethora of terms' used in this field, also decide that 'alternative conceptions' is the most appropriate term for the understandings that children have, whilst noting that 'Not all researchers, however, agree that the term misconception should be disregarded' (p179). Meanwhile Dove (1998) reviews usage of some of the terms noted above, together with, 'children's science', 'preconceptions', 'untutored beliefs', 'intuitive notions', 'ideas' and 'errors' (p184) before also deciding to use the term 'alternative conceptions'. | |
| Much of the discussion of terminology has centred on the ways in which children form ideas about science and the ways in which these ideas are retained, even if they differ from consensus views in science (or 'final form science' - Duschl, 1990) (Driver et al, 1985, 1994b). These can rightly be called 'alternative conceptions' since they are conceptions of the science derived from the experiences of the pupils. | Formatted: Font: 12 pt Deleted: However, m |
| However, the instances observed in textbooks and other similar sources cannot be described as 'alternative conceptions' since, while they may have first developed as a child's evolving view of science, they may well have come from other sources as well, such as erroneous information written elsewhere, or older consensus views, now superseded. They may derive from the author's limited understanding, from poor attempts to simplify ideas for their pupil-readers, or by inadequate attempts to couch their writing to address the views of science that pupils are likely to have, the | |
| <u>'children's science' of Gilbert et al (1982, p623).</u> Where they clearly differ from today's scientific consensus they can best be described as 'errors', however the ways in which they are written in textbooks and their widespread usage indicates that many of these errors are not simple mistakes, but are deep-seated and widely 8 | Deleted: |
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held amongst the writers, which is why the term 'misconception' will be used for these instances in this paper hereafter.

Research into misconceptions in science education has a long track record, with prominent publications in the 1980s (Gilbert & Watts, 1983; Driver et al, 1985; Gunstone at al, 1988) and the 1990's (Driver et al, 1994a, 1994b, Wandershee et al, 1994). Much of this work has focussed on biology, chemistry, physics and space science; nevertheless, there is a small body of work on misconceptions in earth science, discussed below.

EARTH-SCIENCE MISCONCEPTIONS: COMPARISONS BETWEEN THE LITERATURE AND THE TEXTBOOK/SYLLABUS SURVEY FINDINGS

Little analysis of the misconceptions in the earth science content of published textbooks has been carried out previously. Thus the list of more than 500 misconceptions from the textbook and syllabus surveys has been subjected to analysis to identify those areas of earth science most prone to misconception. This textbook and syllabus data is important, as most textbook and syllabus writers are themselves, or have been, science teachers, so the analysis provides a guide to the misconceptions held more generally by science teachers in England and Wales. Such information on the misconceptions of practicing science teachers is not readily available since most research into earth science misconceptions to date has focussed on primary (elementary) and secondary (high school) pupils, on college students, or on trainee (pre-service) teachers from a range of countries.

<u>A comparison of the textbook/ syllabus</u> analysis with the published earth science misconception work, largely from from pupils, students and trainee teachers, has enabled a series of similarities and differences to be identified. The textbook/ syllabus data was categorised into a number of earth science areas and most of them attracted at least some research allowing comparisons to be made.

Key works relating to earth science misconceptions are listed in Table 3 whilst earlier works are summarised in Thompson (1986). The main areas of comparison/ contrast between the research literature and the textbook/ syllabus survey are described below and tabulated in Table 4.

Table 3 hereabouts. Key references relating to earth science misconceptions.

Table 4 hereabouts. Comparison between earth science misconceptions common in the literature and those most frequently found in the textbook/ syllabus surveys.

Minerals, rocks and fossils

The concepts of rocks, minerals and fossils provide key building blocks of geological understanding. However, many pupils bring with them a range of misconceptions about them, as indicated by Happs (1982), 'The term 'rock' is largely used in a non-scientific way ...' (p14) and Dove (1996), 'the [assessment] activities provided ... evidence to suggest that the term 'rock' is widely misunderstood among students' (p269).

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The textbook misconception data collected has been categorised into a number of earth science areas and most of these have attracted at least some research,

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Concerning minerals, Blake (2004) noted that the term 'mineral' was a problematic concept for 9-11 year old children whilst Happs (1982) found no 11-18 year old students that were able to use the term 'mineral' in the scientific sense.' (p18).

Children's understanding of rocks has been studied since Piaget (1929) reported that many young children thought that rocks, were created by men or God whilst others thought they grew from seeds in the soil. Studies since have been summarised by Dove (1998, p185) as showing that pupils of all ages regarded rocks as, 'dull, heavy, large, dark material ... [and] colour was also an important criterion'. Children also confuse rocks with minerals (Happs, 1985a; Oversby, 1996). Meanwhile Ford (2003) found that, unlike experienced earth scientists, most primary (elementary) children in his survey (87% in the group studied using a rock kit) looked for properties that provided no evidence of the mode of rock formation. Blake (2004) summarised his work and others as, 'Children's alternative conceptions for describing and classifying rocks centre on simple physical properties such as colour or shape and reveal only limited ideas about the origins of rocks.' (p1857). Meanwhile Happs (1985b) has shown that even when children do make the observations that would allow them to interpret how rocks were formed, they can often misinterpret these clues, and come to incorrect conclusions. Misconceptions about rocks are particularly problematical when children are asked to classify and identify rocks, so it is not surprising that when trainee (pre-service) teachers were asked to teach rock identification, they showed relatively high anxiety levels (Westerback et al, 1985). These studies reveal the need for systems to teach about rock characteristics and classification using intrinsic features that provide evidence of the rock-forming processes, such as that described by Hawley (2002).

Oversby (1996) in researching understanding of fossils, has shown that many pupils and pre-service teachers, when given descriptions of fossils and non-fossils, were unable to distinguish between them. He concluded that, 'A source of the confusion may be that pupils have been taught that a petrified body is an example of a fossil; this is then reinterpreted as a belief that only petrified bodies are fossils.'(p 94). This comment links with two similar examples found in the textbook survey.

The textbook survey showed marked similarities between the misconceptions concerning minerals, rocks and fossils found in textbooks and those described in the literature. Eleven examples of misconceived rock definitions were found in the textbook survey (including confusion between 'minerals' and 'rocks') together with confusion about the meaning of 'hardness' as applied to rocks. Confusion was also found in textbook-writers around processes of fossilisation, similar to those found by Oversby (1996) for example, suggestions that there is only one method of fossilisation. Since textbook writers were once pupils and later were trainee teachers, these similarities are not surprising.

Sedimentary, igneous and metamorphic processes

Research into <u>understanding of</u> rock-forming processes has ranged from broad studies of a range of processes and their rock products to those that focus on specific processes. Dove, in her 1997 survey, investigated student ideas about weathering and erosion and uncovered a range of misconceptions. As Dove (1997, 1998) describes, this is probably because the terms have altered in meaning over time and can still be interpreted in different ways by textbooks of today.

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Nevertheless, the definitions are clear in most authoritative texts used by earth scientists, as shown in Table 2.

Many of the misconceptions identified by Dove were also found in the textbook/ syllabus surveys, where confusion between the terms 'weathering' and 'erosion' (Table 2, Section A) provided the greatest incidence of misconception recorded. It is because processes of weathering and erosion generally act together that, if the processes are to be properly understood, they need to be distinguished so that the results of combining different processes in different ways can be interpreted. This fine point may be lost on a non-specialist teacher, which is why a comparable chemical example is added to Table 2 in an attempt to indicate to a non-specialist the scale of the issues involved.

The fact that freeze/ thaw weathering requires many cycles of freezing and thawing (Table 2, J) is not made clear in many science texts. This misconception can be compounded by the findings that many pupils expect water to shrink on freezing, rather than to expand (Cosgrove and Osborne, 1983). They recommend that teachers should demonstrate to pupils that water does expand on freezing, to underpin their correct understanding of the freeze/ thaw weathering process.

The evidence for processes of rock-formation, and the environments in which the rocks formed, is preserved in the rocks. Thus misunderstandings about rock-forming processes will be reflected in misunderstandings about the features preserved in rocks, and vise versa. Happs (1982) found a range of misunderstandings in children about the concepts of sedimentary, igneous and metamorphic rocks such that Driver et al (1994b) summarised his work as, 'Very few children ... appreciated the relationship between sedimentary rocks and the sedimentary processes by which they are formed. ... Most children ..., when confronted with specimens of igneous rocks had no ideas on formation to offer ...' and, '... the word 'metamorphic' was associated by most children with metamorphosis in animals ...' (p113). Misunderstandings like these can be carried right through to adulthood as shown in Stofflett's (1993) work with pre-service primary (elementary) teachers, commenting that, 'The misconceptions exhibited in this study [about rocks and their formation] were, quite frankly, appalling.' (p230). Stofflett (1994) also showed that the, 'average teacher candidate understood only 18 percent of the concepts [relating to rockforming processes] presented.' (p495). Kusnick (2002), in another survey of preservice primary teachers, showed that, 'Students hold a surprising number of misconceptions about how rocks form.' (p31), commenting that, 'a startling number of students described rocks as forming by processes that no geologist would recognise.' (p37) and concluding that, 'students need schooling experiences which build a basis for conceptual understanding ...' (p38).

Ford (2005) researched understanding of the rock cycle as a whole and found that 11-12 year old US pupils, having previously learned about the rock cycle, rarely mentioned it in their explanations of the formation of different types of rocks. She found that,

'students did not grasp the purpose of instruction about the rock cycle. Instead their responses indicate they perceive the rock cycle as the *cause* of rock formation, rather than a model representing relationships between rock categories and their formation. For example, when asked how a rock formed,

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Deleted: Earth scientists study rockforming processes to gain understanding of the evidence preserved in rocks of the processes that formed them and the environments in which they formed. one student responded, "It went through the rock cycle" much as laundry goes through a wash cycle – something that is done to a rock to change it.' (p375).

Meanwhile, Kali et al (2003) have shown that the type of thinking needed to understand the rock cycle and related systems thinking, involves high order thinking skills – but thinking skills that can be developed through appropriate teaching strategies. Meanwhile Sibley et al (2007) have shown that novel approaches (in their case, by asking students to link processes in a 'box diagram') can be effective in teaching cyclic thinking of the type needed to understand the rock cycle.

Work specifically related to the understanding of igneous processes has been reviewed by Dove (1998) who found a, 'tendency for students to confuse earthquake with volcanic activity.' (p187) – going on to stress that, 'only a minority of earthquakes are caused in this way.' (p188). Some studies, such as that of Lillo (1994) and Dahl et al (2005) have shown the misunderstanding that magma that erupts through volcanoes originates in the Earth's core – when virtually all magma is thought to originate in the upper portion of the mantle or crust (Hancock & Skinner, 2000). Researchers have also found that US college students, 'believed that volcanoes only occur on islands, that they are associated with warm climates, and that volcanoes only occur along the equator, among other ideas.' (Libarkin et al, 2005, p24). These findings were supported by Marques (1988) for Portuguese students of ages 10-11 and 14-15.

Given the widespread misconceptions about rock-forming processes found in these studies, it is not surprising that misconceptions were also common in the textbook materials surveyed, with errors around the rock-forming processes forming 40% of the total data: sedimentary – 24.1%; igneous – 7.5%; metamorphic – 8.3%. The misconceptions were wide-ranging and the most common concerned lack of understanding about how sediments become cemented to produce sedimentary rocks (indicating, for example, that sedimentary rocks are formed by compression only), confusion about limestone and chalk formation (eg. chalk is made from skeletons), misunderstandings about sediment and soil (eg. sediment grains are always small), about where magma comes from (suggesting magma comes from the core) and how granites and basalts form, and misconceptions about the causes and results of metamorphism (indicating that metamorphism happens when rocks are buried). Consensus scientific views on these topics are given in Table 2.

Geological time, correlation and dating

Children's understanding of geological time was investigated by Ault (1982) and this work has been followed up more recently by a number of researchers. Schoon (1992, 1995) showed that nearly a third of the US primary (10-11 year old) pupils and a fifth of the pre-service primary teachers in his surveys thought that dinosaurs lived at the same time as cavemen. Trend (1998) studied the understanding of upper primary (10-11 year old) UK pupils showing that although the children had, 'a general awareness of major events such as the Ice Age and moving continents ... a clear chronology is almost entirely lacking.' (p973). Trend went on to study understandings of geological time among UK pre-service primary teachers (2000), concluding that, 'Trainee teachers ... are more comfortable and imaginative with their teaching of history than with their geology, despite the parallels.' (p539). In further commentary, Trend (2001), 'proposed that the nature and quality of UK society's engagement with

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geoscience phenomena is constrained by an all-pervasive confusion with deep time, both relative and absolute.' (p196). He also found that, 'Primary teachers do not have a secure grasp of deep time either in absolute or relative terms.' (p215) indicating that they are neither secure with the magnitude of geological time (the big numbers) or the ordering of time (the relative dating and correlation of geological events). This work is supported by that of Hidalgo and Otero (2004) who showed that students find it difficult to remember timed events in isolation. While they are sometimes able to deduce the order of geological events from other information, they 10 find it very difficult to conceptualise long periods of time. Libarkin et al (2005) found 11 that US college students held a number of misconceptions about the dating of the 12 formation of the Earth and the formation of life. In further work Libarkin & Anderson 13 (2005) found that students had poor ideas of the scale of geological time, the 14 occurrence of events in geological history and absolute age dating. Meanwhile, Dahl 15 et al (2005) working with US practising teachers, found that they were fairly 16 comfortable with relative dating, but not comfortable with allocating dates to 17 geological events. Meanwhile Dodick and Orion (2003) have shown that most Israeli students in their study did not have the cognitive skills to cope with the concept of 18 geological time until they reached the age of 12 or older. 19 20

Together, this research indicates that the population at large does not generally have a 'feel' for geological time and that while younger children have difficulty with both relative time (sequencing events) and absolute time (allocating ages to the events) older people are more able to cope with relative time, but still find the concept of absolute time difficult to comprehend.

For these reasons, it is crucial for science textbook writers to at least provide correct information. Thus it is unfortunate that they are also prone to error in this area, producing both numerical errors (eg. that radiometric dating might show a rock to be 9000 million years old, ie. older than the solar system) and general misunderstandings (for example, by stating that the age of a rock can be determined from the rock type). In future, the best examples of textbook writing in this area will respond to Trend's (2001) recommendation to include, 'a carefully designed deep time framework that comprises a small number of key major geo-events ...' (p192) in their work.

Earthquakes and the structure of the Earth

Leather (1987), through his study of UK children's understanding of earthquakes at different ages, has shown how their misconceptions diminished with age and the scientific view became dominant. So, whilst most 11 year olds thought earthquakes were related to hot countries, were directly related to volcanic activity, and could never occur in Britain, they had mainly lost these views by the age of 17. However, Schoon (1992, 1995) has shown in separate surveys that nearly a third of both US primary pupils (10–11 year olds) and pre-service primary teachers thought incorrectly that Chicago could not be damaged by an earthquake; this misconception therefore did not diminish with age. In Israel, a country prone to earthquakes, 77% of the 12–16 years old students surveyed were unaware that their school was situated in a high risk area (Rutin & Sofer, 2007) and many had little idea of the correct response to a future earthquake.

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That many primary children (5–11 year olds) have little understanding of the causes of earthquakes has been supported by the work in the US of Ross & Shuell (1993) and in the UK by Sharp et al (1995). The mythological and supernatural views of the origin of earthquakes held by some pupils in Taiwan have been studied by Tsai (2001).

Lillo (1994) researched 10–15 year old Spanish children's understandings of the internal structure of the Earth by asking them to draw pictures. These showed that, whilst most students thought the Earth was formed of concentric layers, and this view increased with age, many of all ages thought the hot molten core was the source of the magma involved in volcanic eruption. Many students also drew the thicknesses of the layers wrongly, with the crust often much too thick. This paralleled a similar misconception of UK practising science teachers (King, 2000) and US college students (Steer et al, 2005). Steer et al (2005), having identified this misconception, used practical model making and peer group discussion to teach the correct dimensions of the Earth's core, mantle and crust, with a high level of success, as shown by post-course assessment several weeks after completion of the course.

Marques and Thompson (1997a) asked Portuguese students to indicate on a diagram where they thought the densest materials in the Earth would be found, and many of primary age indicated near the South Pole. A significant, but reduced number of older students also showed this misconception.

Research into the understanding of earthquakes and the structure of the Earth by older (college) students and teachers has been limited. However Libarkin et al (2005) have shown that, whilst most of the US college students they surveyed related earthquakes to plate tectonics,

'Alternative explanations for the primary causes of earthquakes included the influence of heat, temperature, climate, weather, people and animals ... gas pressure, gravity, the rotation of the Earth and processes in the Earth's core, "exploding soil" and volcances ...' and the expanding Earth (p23).

They also found that, when questioned about the interior of the Earth, 'almost all students mixed physical state (lithosphere, asthenosphere, mesosphere, inner core, outer core) and chemical boundary (crust, mantle, core) terms, indicating a lack of understanding of the basis of subdividing the Earth's interior.' (p24).

King (2000) surveyed practising UK science teachers and found high levels of misconception about the states (solid, partial solid, partial liquid or liquid) of the different layers of the Earth and of the thickness of the crust. Poor understanding was also shown of how the density of the Earth changes with depth and where different depths of earthquakes are likely to be found.

The misconceptions about earthquakes and Earth's interior held by younger children were generally not found in UK science textbooks. However those misconceptions prevalent in US college students and UK teachers were common in the science textbooks, Confusion about the physical state of Earth layers (such as statements that the mantle is liquid, when it is almost entirely solid) and their thickness (for

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International Journal of Science Education

example, the crust being shown much thicker than it actually is) was particularly common in both the literature relating to older students and the textbook survey.

Plate tectonics

Margues and Thompson (1997b) researched the misconceptions about plate tectonics held by 16-17 year old Portuguese students after they had been taught about plate tectonics in the classroom. They found that many students had developed little understanding of how continents and oceans form and develop. They also had poor understanding of the term 'plate', of how plates move, or the causes of this movement. Meanwhile King (2000) showed that practising UK science teachers had little understanding of how earthquake and heat flow distributions on Earth were linked to plate tectonics. Libarkin et al (2005) showed that some US college students (mainly 19–20 year olds), 'were unsure about the location of the Earth's tectonic plates, believing them to be somewhere below the surface ...', whilst a few, 'place tectonic plates at the Earth's core or in the atmosphere ...' (p23). Many of the students surveyed, 'were unable to conceive of tectonic plates relative to their own space, and most preferred to disconnect tectonic plates and their movement from the Earth's surface.' (p23), whilst few students connected volcanoes with plate tectonics. Meanwhile Libarkin & Anderson (2005) found that most US college students, 'are exiting courses with a poor understanding of the location of tectonic plates.' (p394) and Libarkin (2006) commented on, 'the fact that most [US] college students would claim that they have learned about gravity or plate tectonics in prior coursework does not mean that they fully understand these phenomena.' (p9).

Most instances of misconception in the textbook/_syllabus surveys related to confusion between the thin crust and the thicker lithosphere that forms the plates, a finding that did not figure strongly in the research literature. However, there were also many single instances of misconception in the textbooks (such as indicating that the continental crust was dragged down in subduction, when it is much too buoyant for this to happen), reflecting the confusion identified in the literature noted above.

History of geology

Only a small number of instances of misconception was identified in the textbook and syllabus surveys for this aspect of the curriculum, and there is also little coverage of misconceptions in this area in the literature.

Economic geology

Leather (1987) asked UK pupils what oil formed from, and found that, 'Dead sea creatures (or animals) ... [was] the most popular idea at all ages, and plants, vegetation, leaves or seaweed ... [comes] a strong second.' (p105), although some pupils thought oil formed from water, and others from coal. Few of the pupils he surveyed had a clear idea of how oil was trapped underground,

'The most popular view was that oil is contained below the sea bed in some sort of hollow, described as pockets, holes, spaces, potholes, gaps, cavities, crannies, pools, ponds, crevices, chambers and caves. This answer was given by 16% of the eleven year olds, 35% of the fourteen year olds and 24% of the seventeen year olds. A less common misconception was that oil collects on the sea bed (14% of eleven year olds)' (p106)

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These findings relate closely to the misconceptions about oil noted in the textbook/ syllabus surveys. The textbooks also refer to oil being formed from animals/ creatures (when the consensus view is that almost all oil and gas is derived from plant material and bacteria, see Table 2). The textbook survey identified several confused diagrams and statements about oil/ gas trapping mechanisms that relate to the misconceptions of pupils, noted above.

Atmosphere and ocean

The atmosphere and ocean only have limited coverage in the science curriculum of England and Wales and therefore only have limited coverage in the textbooks and syllabuses that relate to the curriculum. Thus only a relatively small number of 'errors/ oversimplifications' was recorded in the surveys (20 in a total of 531 instances, or 4% of the data).

Since the coverage of the atmosphere and ocean, and particularly concerns about the greenhouse effect and global warming, form a key part of the earth science and environmental science studies of pupils across the globe, research into misconceptions in these areas has been extensive, and too large to cover adequately in this discussion.

<u>Nevertheless the</u>, environmental research <u>literature indicates</u> widespread misconception about environmental issues amongst school students <u>and</u> pre-service and practising science teachers. The textbook instances found by the survey, reflected some of the misconceptions noted in the research, relating <u>particularly</u> to incomplete carbon cycles and global warming diagrams showing the atmosphere reflecting heat.

The level of misconception relating to the atmosphere and ocean identified by the survey was smaller than for other areas of earth science. Thus it does seem that UK textbook-writers are more comfortable with this area of the curriculum than with those areas relating to geological science in particular. The syllabus surveys (King at al, 1998, 2004; King and Hughes, 2007), certainly showed poorer coverage of geological science than 'environmental science' concepts.

DISCUSSION AND CONCLUSIONS

Most of the instances of misconception covered by this analysis were identified through a survey of all the science textbooks that were being used in secondary (high) schools in England and Wales in 2002. The survey compared the content of the textbooks with the requirements of the government National Curriculum for science and found poor coverage. During the survey a total of 453 instances of 'error/_oversimplification' were noted. This poor situation is mirrored in the US where the Project 2061 textbook survey (Kesidou & Roseman, 2002; Stern & Ahlgren,

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(p76).

Groves and Pugh (1999) noted that, 'Previous studies revealed that students hold many misconceptions relating to such issues as global warming, ozone depletion and acid rain.' (p75) and summarised the work of Boyes et al (1993) as, 'many students appeared to confuse certain major environmental problems (the greenhouse effect, ozone depletion, loss of biodiversity, air and water pollution, and nuclear power) in terms of causality, consequences and in ways to alleviate these problems (p75). Groves & Pugh also cite the work of Arons et al (1994) as research, ¶ that included elementary level, physical science, and geography preservice teachers [which] found that these groups held many misconceptions about atmospheric phenomena, and these researchers expressed concern about the ability of teachers to instruct their own students correctly since they, themselves, did not have proper understandings ...

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1 2 2002; Stern & Roseman 2004) also reported poor content, particularly for the earth 3 sciences. Sellés-Martinez (2007) has found a similar situation in Spanish textbooks 4 used in Argentina. The situation could be summarised in the terms used by Arthur 5 (1996) of, 'Lies, dam lies and books on geology' (p.289). The limited research 6 evidence shows that in countries where there is a 'free press' (no government control 7 over textbook content), the earth science content of broad science textbooks is poor 8 and prone to misconception. However, the situation can be improved by surveys like 9 this. As a result of wide circulation and dissemination of the report, several 10 publishers asked for their materials to be proof-read before publication, and this has 11 continued to today. 12 13 That scrutiny of syllabuses and examinations can be effective, is suggested by the 14 reduction in the level of misconception shown by three reports over time (King et al, 15 1998, 2004; King and Hughes, 2007), following their wide circulation and publication 16 of the findings. 17 18 Textbooks play a central role in daily teaching, (as indicated by the research 19 described in the 'Science textbooks and their importance' section above) and it is 20 likely that syllabuses and examination papers play an even more crucial role. The 21 work of Ball and Cohen (1996) has highlighted the importance of curriculum materials in developing the understanding of teachers and in influencing teaching 22 23 and learning. They comment, 24 'We know far too little about how written materials might support teachers' 25 learning ... [nevertheless] ... we propose the creation of curricula that would 26 help teachers better enact curriculum in practice ... curriculum materials could 27 offer teachers opportunities to learn in and from their work.' (p8). 28 The analysis of the misconception data for science textbooks and syllabuses in 29 England and Wales summarised in this paper has revealed the misconceptions 30 that are most prevalent amongst writers of science materials. Misconceptions 31 are particularly common in the areas of sedimentary processes/ rocks, 32 earthquakes/ Earth's structure, and plate tectonics. Study of Earth science 33 misconceptions forms an important part of the research literature in earth Deleted: key 34 science education, summarised by King (2008a). 35 Deleted: in press b 36 Comparison between the earth science misconceptions identified in the literature 37 and those noted in the textbook/ syllabus surveys show contrasts for different age 38 levels. Where much of the published misconception work has focussed on primary 39 (elementary) children, few of the misconceptions identified in the literature have been 40 exhibited by the writers of the secondary (high school) textbooks/ syllabuses 41 surveyed. However, where the published misconception work has focussed on 42 mainly on college students and trainee (pre-service) teachers there is a much closer Deleted: 43 correlation. With a high level of misconception in earth science understanding of Deleted: and practising 44 trainee teachers, practicing teachers and textbook writers, there is a major task 45 ahead to improve the education of all these groups. 46 47 The correlation between the misconceptions of college students/ trainee (pre-48 service) teachers and the textbook/ syllabus survey strengthens the view that the 49 textbook/ syllabus survey provides a useful reflection of the misconceptions of 50 practicing science teachers in the UK. This is because most textbook/ syllabus 51 52 17 53 54 55 56 57 58 59 60

| literature, since there are few opportunities to probe the earth science understanding | |
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| of classroom science teachers. The insights provided by the textbook/ syllabus survey therefore have increased importance if they provide a better snapshot of the | |
| misconceptions involved in normal classroom earth science teaching than other | |
| elements of the literature on earth science misconceptions. | |
| However, one of the disadvantages of textbook/ syllabus surveys is that they do not | |
| provide opportunities for analysis of how the misconceptions of the writers developed. They may have come from the teaching the writers themselves received, | |
| from erroneous textbook sources, or from overzealous attempts at oversimplification | |
| for their pupil readers. Study of how textbook-writers developed their misconceptions | |
| would provide a valuable, if problematical, line of future research. | |
| One way of improving education is to ensure that curriculum materials are of high | Deleted: t |
| quality and are error-free. This analysis has shown that this is not been the case in | |
| the past with many of the materials written for the earth science component of the secondary (high school) science curriculum in England and Wales. Meanwhile, | |
| similar situations seem to pertain in US and Spanish teaching materials. The detailed | |
| review of the misconceptions in the published materials provided by the reports (King | |
| et al, 1998, 2002) and the analysis and review of the data provided by this paper can | |
| provide a foundation for future improvement in all these cases. Nevertheless, continued scrutiny will be necessary, so the anecdotal evidence that this scrutiny can | |
| be effective, is reassuring. | |
| Table 2 provides the background that will allow future science textbook writers to | |
| Table 2 provides the background that will allow future science textbook writers to correct and improve their writing of earth science materials and so offer the | |
| opportunity for these improved materials to address the earth science | |
| misconceptions of teachers and pupils alike. So, rather than promulgating earth science misconceptions, as in many cases in the past, textbook writers now have the | |
| opportunity to improve teaching and learning in this area of key importance to the | |
| science curriculum and to the knowledge and understanding of citizens of the future. | |
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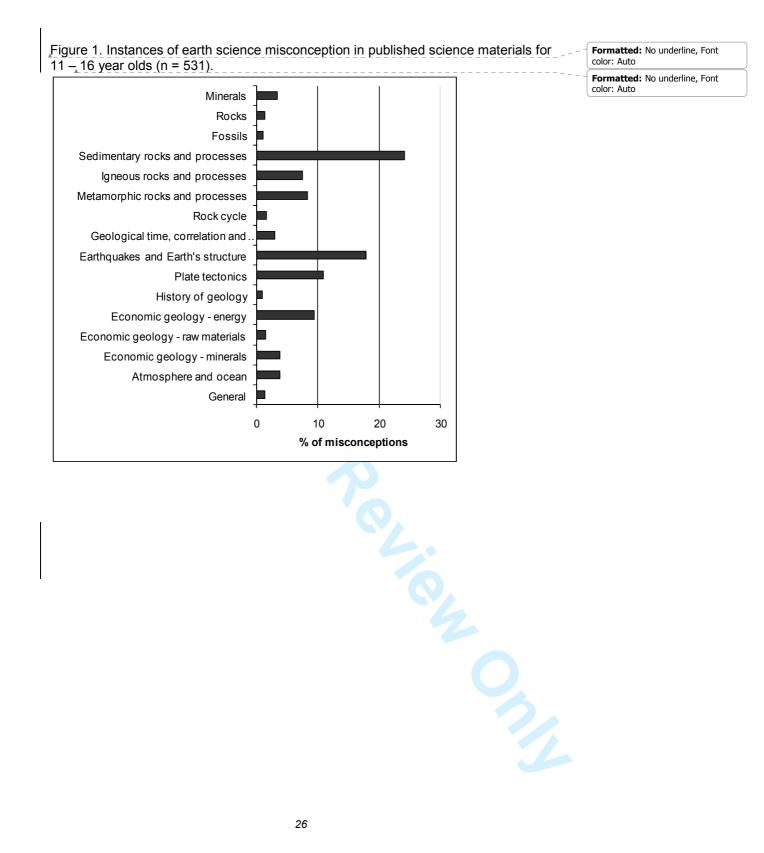
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| Weatheri | 7.0% | away by the air, | The | place and so no solid | the | N. 1 | Formatted | |
| ng/ | | wind and rain. | breakdown of | material is removed. | dissolving of | $\sim M$ | | |
| erosion | | This is called | rocks and | Weathering causes | salt and the | - AK | Formatted | ([I |
| confusion | | weathering.' (O1 - | minerals at the | chemical breakdown or | 'dissolving' | ZIVH. | Formatted | [[] |
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| В. | 35 | 'The earth's crust | (The | The mantle is almost | Considering | | Formatted | (r |
| Indicating | 6.6% | is split into | asthenosphere | entirely solid, as shown | that glass is | 5/ | | [|
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| magma' | | 136 – textbook | upper mantle | mantle between the | | V | Formatted: No und | orlino Font |
| (see also | | series for 11-14 | immediately | solid lithosphere above | | | color: Auto | ennie, ronc |
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| ʻsemi- | | | in solid state | flow very slowly. | | | Formatted |
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| are made of crusť, | | the Earth's crust consists of a | p284) 'Lithosphere. | there is a physical boundary between the | | 11/1 | Formatted |
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| animals, eg. 'oil | | creatures whose shells and | bacteria.' | crust. The oil-producing plankton is mostly | | · · · | Formatted | |
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| creatures' | | for 11 – 14 year | _fine-grained | | | | Formatted | [148 |
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| particles | | rocks can | Skinner, 2000, | energy of the | | <u>``</u> | Formatted | [17 |
| that settle | | produce particles | p944) | transporting medium | | | Formatted | |
| out of | | of rock which can | Weathering. | falls. | | ' | | [17 |
| water' | | settle_out_from | The group of | Weathering involves a range of processes that | | <[] | Formatted | ([17 |
| and 'there are | | rivers as sediments e.g. | processes, such as the | usually act together. | | · · · | Formatted | [17 |
| just two | | limestone. | chemical | Several different | | | Formatted | [17 |
| sorts of | | mudstone, rock | action of | physical, biological and | | | Formatted | [17 |
| physical | | salt.' (L3 – 33 – | rainwater and | chemical weathering | | 1 | Formatted | |
| weatherin | | science | of plants and | processes are involved. | | | | [176 |
| | | | | | | | Formatted | [17] |

| g'_or | examination | bacteria and | | | ` | Formatted: No und | erline |
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| 'there are | syllabus for 16 | the | | | | Formatted: No und | erline |
| just two | year olds) | mechanical | | | | Formatted: No und | erline Font |
| sorts of chemical | | action of | | | | color: Auto | ennie, i onc |
| weatherin | | changes of temperature, | | | 1 | Formatted: No und | orlino |
| g' | | whereby rocks | | | 1 | / | |
| 9 | | on exposure to | | | , , | Formatted: No und | erline, Font |
| | | the weather | | | | color: Auto | |
| | | change in | | | 14 | Formatted: No und | erline, Font |
| | | character, | | | 141 | color: Auto | |
| | | decay and | | | 14/ | Formatted: No und | erline, Font |
| | | finally crumble | | | | color: Auto | |
| | | into soil' (AGI, | | | | Formatted: No und | erline, Font |
| | | 1962, p536) | | | \$11 | color: Auto | |
| A A . | 0 <u>'Metamorphic</u> : | 'Regional | Widespread (regional) | Thinking | 1 | Formatted: No und | erline, Font |
| Indicating 1.9 | | metamorphism | metamorphism that | that water | | color: Auto | |
| that | and sedimentary | . The | produces slates, schists | can boil at | | Formatted: No und | erline, Font |
| metamor | rocks may be | recrystallisatio | and gneisses requires | 50 °C at | | color: Auto | |
| phism is | buried. Heat and | n of pre- | regimes of very high | normal | | Formatted: No und | erline, Font |
| caused | pressure change | existing rocks | compression and | (atmospheri | | color: Auto | |
| by | these rocks. This | in response to | heating These | c) pressures | | Formatted: No und | erline, Font |
| overburd | change makes | simultaneous | conditions only occur | | 1 | color: Auto | |
| en | metamorphic | changes of | when plates collide. | | 1 - | Formatted: No und | erline, Font |
| pressure, | rocks.' (N3 - B9, 38 – textbook | temperature, lithostatic | There is normally not enough compression or | | (| color: Auto | |
| eg. 'metamor | series for 11 – 14 | pressure and, | heating produced by | | | Formatted: No und | erline. Font |
| phism is | year olds) | in many cases, | burial alone to cause | | <u>,</u> , | color: Auto | |
| caused | 'Metamorphic | shear stress, | metamorphism. | | 1 | Formatted: No und | erline Font |
| when | rocks as those | occurring in | Meanwhile, baking by | | $\langle \cdot \rangle$ | color: Auto | crime, rone |
| rocks are | formed from rocks | orogenic belts | hot igneous intrusions | | \sim | Formatted: No und | erline Font |
| buried | which became | where | can cause localised | | ×. | color: Auto | ennie, ronc |
| and | buried deep | lithospheric | metamorphism. | | `` | Formatted: No und | orlino Font |
| heated' | underground' | plates are | | | | color: Auto | ennie, i onc |
| or | S1/2 – 50 – | converging' | | | N | Formatted | <u> </u> |
| metamor | science | (Allaby & | | | 111 | | [17 |
| phic | examination | Allaby, 1991, | | | 1111 | Formatted | [17 |
| rocks are | syllabus for 16 | p311) | | | 1.11 | Formatted | [18 |
| formed | year olds) | 'Contact | | | | Formatted | [18 |
| by the | | metamorphism | | | | Formatted | |
| pressure | | . The | | | | | [18] |
| of the | | recrystallisatio | | | | Formatted: No und | erline |
| overlying | | n of rocks | | | | Formatted | [18] |
| rocks and heat' | | surrounding an | | | | Formatted | |
| neat | | igneous intrusion in | | | / | / | [184 |
| | | response to | | | , í | Formatted: No und | eriine |
| | | the heat | | | 11 | Formatted | [18 |
| | | supplied by | | | 1 11 | Formatted | [180 |
| | | the intrusion.' | | | 1 11 | Formatted | |
| | | (Allaby & | | | | · | [18] |
| | | Allaby, 1991, | | | 11/1 | Formatted | [18 |
| | | p83) | | | 111/ | Formatted | [18 |
| H. The 1 | 0 'The rock surface | The thickness | The crust comprises the | Thinking | \$1/ · | Formatted | ([19 |
| thickness 1.9 | | of the | continental crust and the | that skin is | [/^_ | | |
| es of | most 10 | lithosphere | oceanic crust, with a | 0.1 mm | í / | Formatted | ([19 |
| Earth | kilometres thick.' | varies | mean thickness of | thick (skin | 11 | Formatted | [19 |
| layers are | (H2 - BB, 130 – | between about | around 18 km. The crust | actually | 1. | Formatted | [19 |
| | textbook series | 80 – 125 km, | is chemically different | averages 1 | 1 | E | |
| given or | | | | | | Formatted | ([19· |

| incorrectl | olds) | an average | boundary, the Moho, is | thick) | Formatted | [196] |
|------------------------|--|-------------------------------|--|---|------------------|----------|
| у | Crust At its | crustal | a chemical boundary. | | Formatted | [197] |
| | thickest it is about 40km.' (H4 – 166 | thickness of 35 km for the | This boundary does not influence plate tectonics. | / | Formatted | [198] |
| | - textbook for 14 | continents and | The tectonic plates are | | Formatted | [199] |
| | – 16 year olds) | 7 km for the | of lithosphere, | | Formatted | ([200] |
| | Earth cross- | | comprising the crust and | | Formatted | |
| | section diagram showing the core | (Duff, 1993, p599) | the outermost mantle and are around 100 km | Ň | Formatted | ([201] |
| | too small and the | (Continental | thick. The lithosphere is | | Formatted | ([202] |
| | crust far too thick. | crust | solid and rigid and the | · · · · · · · · · · · · · · · · · · · | < | [203] |
| | C1 - C 147 - | averaging | boundary between it and the asthenosphere | | Formatted | [204] |
| | textbook for 14 – 16 year olds) | 35km and reaching 70 | beneath is the 1300°C | | Formatted | ([205] |
| | | km in some | isotherm. The | | Formatted | [206] |
| | | places.' (Duff, | asthenosphere is the | | Formatted | [207] |
| | | 1993, p14) | 'weak sphere' of the | < | Formatted | [208] |
| | | The boundary [of the core] | Earth and, although 95 – 99% solid, is able to | · | Formatted | [209] |
| | | with the | flow, affecting plate | `. | Formatted | [210] |
| | | mantle lies at | movement. The base of | | Formatted | [211] |
| | | a depth of | the asthenosphere is | | Formatted | [212] |
| | | c2900 km from the surface | about 350km down. The mantle continues down | | Formatted | [213] |
| | | and the core | to the core/mantle | | Formatted | [214] |
| | | therefore | thereforeboundary at 2891 kmoccupiesdepth, a boundaryover 50between the solidpercent of themantle and the liquidradius.' (Duff,outer iron-rich core that1993, p13)is both mechanical and | | , ' '' Formatted | [215] |
| | | occupies | | | Formatted | |
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| | | | | 1 | | [217] |
| | | 1993, p13) | | | | ([218] |
| | | | chemical. The | | | ([219] |
| | | | mechanical boundary between the liquid outer | | Formatted | ([220] |
| | | | core and solid inner core | N. A. | Formatted | [221] |
| | | | is at 5149 km depth. | N. | Formatted | [222] |
| | | | The centre of the Earth | N. | Formatted | [223] |
| | (Dealer sector) | <u>(0)</u> | is 6371 km deep. | | U ₁ | [224] |
| I10 Misunder1.9% | 'Rocks containing_ metals or metal | Ore. A mineral or rock that | The minerals that make up most rocks contain | Considering | Formatted | [225] |
| standing | compounds are | can be worked | metal compounds, but | seam 1 mm | Formatted | [226] |
| of 'ore', | called ores.' (C3 - | _economically' | are not ores. The term | thick is a | Formatted | [227] |
| eg. 'rocks | B2, 124 – | _(Allaby & | 'ore' has an economic | useful | Formatted | [228] |
| containin g metals | textbook series for 11 – 14 year | Allaby, 1991, p261) | context. A rock or mineral deposit is only | energy resource | Formatted | [229] |
| are called | olds) | | an ore if it is rich enough | | Formatted | |
| ores' | Ores are | | for potential commercial | / | Formatted | ([230] |
| | mixtures of rocks | | exploitation. | , | | [231] |
| | and minerals. | | | · · / / | Formatted | ([232] |
| | (C5 - B1, 104 – textbook series | | | * | Formatted | ([233] |
| | for 14 – 16 year | | | | Formatted | ([234] |
| | olds) | | | | Formatted | [235] |
| J. 9 | 'In cold weather | _'Water | Freezing alone does not | Thinking | Formatted | [236] |
| Misunder 1.7% standing | the water freezes and expands. The | expends on freezing, and | _ cause physical weathering of rocks; | that a plant will die if | Formatted | [237] |
| of | forces generated | through | many cycles of freezing | you forget to | Formatted | [238] |
| freeze/th | by the ice cause | repeated | and thawing are | water it for | Formatted | [239] |
| aw | pieces of rock to | alternations of | necessary. During each | one day. | Formatted | ([240] |
| process, | snap off.' (J1 – | frost and thaw | thaw, water penetrates | | > | <u> </u> |

Page 33 of 130

International Journal of Science Education

| eg. 'rocks | C100 – textbook | in water-filled | more deeply into the | | [Fo | rmatted: No underli | ine |
|---------------------|----------------------|-----------------|---------------------------|----------------|--------------------|---------------------------------|--------------|
| are | series for 11 – 14 | pores and | crack widened by the | | Fo | rmatted: No underli | ine. Font |
| broken by | year olds) | cracks, the | previous freeze, until a | | | or: Auto | -, |
| freezing' | 'Rocks are | rocks are | fragment eventually | | E | rmatted: No underli | ina Eant |
| | weathered by the | relentlessly | breaks off. | ` | | or: Auto | ine, i oni |
| | freezing of water | broken to bits' | The expansion of water | | $\langle \rangle $ | | . <u>-</u> . |
| | ' (B5 – 96 – | _(Duff, 1993, | on freezing, causing this | | | rmatted: No underli | ine, Font |
| | revision guide for | p22) | process, can be | \. | | or: Auto | |
| | 14 year olds) | | demonstrated by | 1 | | rmatted: No underli | ine, Font |
| | | | freezing a sealed | , | | or: Auto | |
| | | | syringe of 10 ml of | | Fo | rmatted: No underli | ine, Font |
| | | | water, (Williams, 1984). | | | or: Auto | |
| K. 9 | 'Limestone is a | 'Limestones | Limestones occur in a | Thinking | E | rmatted: No underli | ine Font |
| Misunder 1.7% | grey rock with a | exhibit the | wide variety of textures | that Iron and | | or: Auto | ine, ronc |
| standings | rough powdery | same variety | and colours. Some are | steel are | | | |
| of | texture. J1 – C99 | of grain sizes, | soft and porous, others | different | | rmatted: No underli or: Auto | ine, Font |
| limestone | - textbook series | textures and | are harder and at hand | metals – | | | |
| and | for 11 – 14 year | sedimentary | specimen scale are non- | and steel is | | rmatted: No underli | ine, Font |
| chalk, eg. | olds) | structures as | porous (but can be | mainly | | or: Auto | |
| 'limeston | (Chalk: A soft | siliclastic | porous at a larger scale | carbon | Fo | rmatted: No underli | ine |
| e only | crumbly rock | deposits | because of cracks and | | | www.atted. No. undouli | ina Fant |
| | composed of the | [conglomerate | fissures). | 5 | 1.11 | rmatted: No underli or: Auto | ine, ront |
| has grey | calcium carbonate | s, sandstones, | | 1 | | | |
| porous forma' or | shells of | | Chalk is a type of | | | rmatted: No underli | ine, Font |
| forms' or | | mudstones, | limestone formed mainly | | COL | or: Auto | |
| 'chalk is | prehistoric sea | etc.] and, in | of the microscopic | | | rmatted: No underli | ine, Font |
| made of | animals. H2 - BB, | addition, | plates of planktonic | θ ₁ | col | or: Auto | |
| the | 93 – textbook | _others not | single celled plants (ie | | Fo | rmatted: No underli | ine, Font |
| skeletons | series for 11 - 14 _ | exhibited by | they are microscopic | | 11.11 | or: Auto | -, |
| of sea | year olds) | siliclastic | plant remains) | 11 | E | rmatted: No underli | ino Eont |
| creatures' | Chalk is one form | deposits. | | | 2 1 1 1 1 | or: Auto | ine, ronc |
| | of calcium | (Hancock & | | ų. | 말음말 눈 | | |
| | carbonate | Skinner, 2000, | | | | rmatted: No underli or: Auto | ine, Font |
| | Limestone is the | p605) | | | 5899 > | | |
| | most important | 'The | | | | rmatted: No underli | ine, Font |
| | form of calcium | Cretaceous | | | col | or: Auto | |
| | carbonate The | chalks are | | 1 | Fo | rmatted: No underli | ine, Font |
| | third form of | composed | | 1 | col | or: Auto | |
| | calcium carbonate | largely of | | 1 | EO FO | rmatted: No underli | ine. Font |
| | is marble.' N4 - C, | coccoliths | | | | or: Auto | |
| | 121 – textbook | (Tucker, 1982, | | | | | |
| | series for 14 -16 | p155) | | i. | | rmatted: No underli | ine |
| | year olds) | 'Coccolithopho | | I | | rmatted: No underli | ine, Font |
| | | rids are | | 1 | col | or: Auto | |
| | | planktonic | | 11 | E Fo | rmatted: No underli | ine, Font |
| | | algae which | | 1 | col | or: Auto | |
| | | have a | | 1 | Fo | rmatted: No underli | ine |
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| | | calcareous | | | col | or: Auto | |
| | | plates called | | | Fo | rmatted: No underli | ine, Font |
| | | coccoliths. | | | | or: Auto | |
| | | (Tucker 1982, | | | En En | rmatted: No underli | ine Font |
| | | p111) | | | .11.1 | or: Auto | ine, i onc |
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| Indicating that the mantle is | 1.7% | | iquid' section abov | ve | | 5 | Formatted: No underline |
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| | A1.7_70 | | | | | | Formatted: No underline, Font color: Auto |
| semi- | | | | | | 111 | Formatted: No underline |
| liquid or | | | | | | | Formatted: No underline |
| semi- | | | | | | 1 | Formatted: No underline |
| solid M. | 8 | Olivine is a hard, | 'A mineral can | A mineral is an element | Confusing | K | Formatted: No underline, Font color: Auto |
| Mineral/r ock | 1.5% | dense rock Olivine is an | _be defined as | or compound. Thus a mineral has a definite | mixtures and | | Formatted: No underline |
| confusion , eg. | | example of a silicate rock | occurring homogenous | chemical composition, atomic structure and | compounds (eg. a | | Formatted: No underline, Font color: Auto |
| "mineral" and 'rock' | | Olivine is an example of an | solid, inorganically | physical properties (that vary between fixed | iron filings | | Formatted: No underline, Font color: Auto |
| mean the same' | | igneous rock Olivine and | formed, with a definite | limits). A rock is a mixture of one or more | and sulphur with iron | | Formatted: No underline, Font color: Auto |
| | | similar minerals are sometimes | chemical composition or | minerals (or fragments of rocks or fossils) so | sulphide) | | Formatted: No underline, Font color: Auto |
| | | found' (L4 – 11 – question in a science | a definite range of composition, | the compositions and structures of most rocks can be very variable. | | | Formatted: No underline, Font color: Auto |
| | | examination for 16 year olds) | and an ordered atomic | However, some rocks are formed of | | | Formatted: No underline, Font color: Auto |
| | | Some minerals, | arrangement.' | predominantly one | | | Formatted: No underline |
| | | like limestone, are | (Hancock & | mineral, such as | | | Formatted: No underline |
| | | found in rocks on their own.' L8 – | Skinner, 2000, p692) | limestone (largely calcite), quartzite | | | Formatted: No underline |
| | | 47 – textbook for | 'Rock. A | (largely quartz) and rock | | | Formatted: No underline |
| | | 14 – 16 year olds) | | salt (largely halite). Igneous rocks usually | | | Formatted: No underline, Font color: Auto |
| | | d aggregate of | contain more than one mineral. | | | Formatted: No underline, Font color: Auto | |
| | | | minerals or organic matter. The minerals | | | | Formatted: No underline, Font color: Auto |
| | | | may be all of one type or | | | | Formatted: No underline, Font color: Auto |
| | | | of many types …' (Allaby & | | | | Formatted: No underline, Font color: Auto |
| | | | Allaby, 1991, p319) | | | | Formatted: No underline, Font color: Auto |
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International Journal of Science Education

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| | | | | | | Formatted | [249] |
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| | | | | | 11/ | Formatted | [[251] |
| N. Basalt 8 | Molten rock | 'Basalt, a dark- | Granite and basalt are | Confusing | #/ / | Formatted | |
| and 1.5% | which emerges | _coloured, fine | chemically very different | caustic soda | | | <u> </u> |
| granite can form | through volcanoes is | grained extrusive | and so cannot change from one to the other. | (sodium hydroxide) | | Formatted | [253] |
| from the | called lava. As | igneous rock | When the mantle | with | | Formatted | [254] |
| same | this cools it forms | containing | partially melts, dark | common | 1 | Formatted | [255] |
| magma, | a variety of solids | not more than | magma forms. This iron- | salt (sodium | -11 | Formatted | [[256]] |
| eg. 'a | and these are | 53 wt% SiO ₂ ' | rich, silica-poor magma | chloride) | 11 1 | Formatted | |
| single | known as igneous | (Allaby & | produces basalt if it | | 11 | | [257]) |
| magma | rock one | Allaby, 1991, | cools quickly at the | | | Formatted | ([258]) |
| can | example is | 34) | surface or coarse- | | 1.1 | Formatted | [259] |
| produce | granite.' (L11 – | 'Granite. A | grained gabbro if it cools | | 12 | Formatted | [[260] |
| granite or | 100 – textbook for | light-coloured, | slowly at depth. When | | | Formatted | |
| basalt'_or | 11 – 14 year olds) | coarse grained | the crust partially melts, | | | | [261] |
| 'granite | Edinburgh Castle | _igneous rock | a paler, silica-rich | | <u> </u> | Formatted | [262] |
| comes from | stands on a 'plug' | ' (Allaby & | _ magma is formed. This | | | Formatted | [263] |
| volcanoe | of granite that was once inside a | Allaby, 1991, p164) | is rarely erupted as lava, but can explode as ash | | 111 | Formatted | [[264]] |
| s' | volcano. N4 - C, | Granites are | or pumice. Usually this | | 11/1 | Formatted | [[265]] |
| 5 | 282 – textbook | intrusive | magma crystallises | | | | |
| | series for 14 – 16 | igneous rocks | slowly underground to | | | Formatted | [266] |
| | year olds) | that contain | form coarse-grained | | (, , ,) | Formatted | [267] |
| | | large amounts | granite. | | 111 | Formatted | [268] |
| | | of silica (SiO ₂)' | | | 1,1 | Formatted | [269] |
| | | (Hancock & | | | | Formatted | |
| | | Skinner, 2000, | | | ~~~ | ` | [[270] |
| | | p464) | | | `````````````````````````````````````` | Formatted | [271] |
| 0. Oil 7 | Coal, oil and | In the North | Most of the gas in the | Thinking | | Formatted | [272] |
| indicated 1.3% | natural gas are | Sea oil | UK was formed from | that | 111 | Formatted | [[273]] |
| as | called fossil fuels. | forms at 3 – | coals deposited as | evolution | 1 111 1 | Formatted | [[274] |
| forming millions | They were made from plants and | 4.5 km depth, gas at 4 – 6 | swamp deposits some 300 million years ago. | happened millions of | 11111 | Formatted | |
| of years | animals that lived | km Burial | Most of the oil and some | years ago | 1111 | | ([275]) |
| ago, eg. | on Earth about | to these | gas were formed from | years ago | | Formatted | [276] |
| ʻoil | 100 million years | depths occurs | algae and bacteria that | | 111 | Formatted | [277] |
| formed | ago.' (N3 B7, 42 - | in areas where | settled on the sea floor | | | Formatted | [278] |
| once in | textbook series | the Earth's | around 140 million years | | 11 11 | Formatted | |
| geologica | for 11 – 14 year | crust is | ago. These formed | | 11/1 | | [279] |
| l time' | olds) | sagging | source rocks that were | | | Formatted | [[280] |
| | Oil was formed | These | heated and compressed | | 1111 | Formatted | [281] |
| | from the remains | processes | to release their oil and | | 1111 | Formatted | [[282]] |
| | of organisms | continue today | gas and are still slowly | | 111 | Formatted | [283] |
| | which lived millions of years | ' (Clark et al. 1997, p3) | releasing them today. | | | Formatted | |
| | ago.' (N1/2 – 38 – | 1997, p3) | | | 1,1 | | [284] |
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| | examination | | | | 11 1 | Formatted | [[286]] |
| | syllabus for 16 | | | | 11/1 | Formatted | [287] |
| | year olds) | | | | $-\frac{\eta_{I}}{\eta_{I}}$ | Formatted | |
| Key: N4 - C. 282. | Reference to textboo | ok, syllabus or e | xamination source of quo | te containing | 11 | \ | [288] |
| 'error/ oversimplifi | | | | | , ', ', | Formatted | <u> </u> |
| * In the past, the t | erm 'erosion' has bee | en used more br | roadly to include weather | ina, but this | · / ' | Formatted | [290] |
| | usage in scientific dis | | | | 1.11 | Formatted | [[291] |
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Page 36 of 130

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| Category | ces relating to earth science misconceptions Key texts | | |
|------------------------|--|---------------------------|--|
| Minerals, rocks and | Piaget, 1929; Ault, 1984; Happs, 1982, 1985a, 1985b; Hawley, 2002; Dove, | | |
| fossils | 1996, 1998; Oversby, 1996; Ford, 2003, 2005 | | |
| Sedimentary rocks and | Cosgrove & Osborne, 1983; Dove, 1997 | Happs, 1982; | |
| processes | · · · · · · · · · · · · · · · · · · · | Driver et al, 1994b; | |
| Igneous rocks and | Lillo, 1994; Dove, 1998; Libarkin et al, 2005; Dahl | Stofflett, 1994; Kusnick, | |
| processes | et al, 2005 | 2002; | |
| Metamorphic rocks and | None specific to this topic | Blake, 2004; | |
| processes | | | |
| The rock cycle | Stofflett, 1993; Ford 2003; Kali et al, 2003; Sibley | | |
| | et al, 2007 | | |
| Geological time, | Ault, 1982; Trend, 1998, 2000, 2001; Dodick & Orio | n, 2003; Hidalgo & Otero, | |
| correlation and dating | 2004; Libarkin et al, 2005; Libarkin & Anderson, 20 | | |
| Earthquakes and the | Leather, 1987; Schoon, 1992, 1995; Ross & Shuell | | |
| structure of the Earth | et al, 1995; Marques & Thompson, 1997a; King, 20 | | |
| | et al, 2005; Steer et al, 2005; Rutin & Sofer, 2007 | | |
| Plate tectonics | Marques & Thompson, 1997b; King, 2000; Libarkin | et al, 2005; Libarkin, | |
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| History of geology | None specific to this topic | | |
| Economic geology | Leather, 1987 | | |
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| | Table 4. Comparison between earth science misconceptions common in the literature and those most frequently found in the textbook/ syllabus surveys. | | | |
|---|--|---|---------------------------------------|--|
| 1 | Category | Misconceptions of children, students Misconceptions identified in the | | |
| | | and teachers commonly cited in | textbook/syllabus surveys in order of | |

| | existing literature | frequency | | Formatted |
|------------------------|--|---|-------------------------------|-----------|
| Minerals, | The terms 'rock' and 'mineral' often | Mineral/rock confusion | $\langle \rangle$ | Formatted |
| rocks and | used in a non-scientific sense and/or | Mineral definition | 11 | |
| fossils | misunderstood | Rock definition | <i>ار ز</i> ار | Formatted |
| | | Rock hardness | / / | Formatted |
| Sedimentary | Confusion between 'weathering' and | Weathering/erosion confusion | /1 | Formatted |
| rocks and | 'erosion' | Formation of sedimentary rocks by | | Formatted |
| processes | Little understanding that | compression only | 1 | Formatted |
| | sedimentary rocks were formed by | Sedimentary definitions | · · | |
| | sedimentary processes | Freeze-thaw mechanism | `~_ | Formatted |
| | | Chalk/limestone confusion | 1 | Formatted |
| Igneous | Erroneous ideas about volcanoes, | Granite forms in volcanoes | 1 | Formatted |
| rocks and | including that their magma | Igneous definitions | $\langle 1 \rangle$ | Formatted |
| processes | originates in the core and that they | Magma comes only from the mantle | $\langle \rangle$ | Formatted |
| | only occur in warm climates or on islands | | | |
| Metamorphic | Metamorphic processes wrongly | Metamorphic rocks formed by | \sim | Formatted |
| rocks and | associated with metamorphosis in | overburden pressure and heat | | Formatted |
| processes | animals | Metamorphic rocks never contain fossils | | Formatted |
| The rock | The rock cycle not understood as an | The rock cycle is continuous | | Formatted |
| cycle | explanatory model | | | Formatted |
| Geological | Most people had poor chronological | Rocks dated by radioactivity of 'rocks' | | |
| time, | understanding of geological events | or fossils | | Formatted |
| correlation | | | | Formatted |
| and dating | | | 1,1 | Formatted |
| Earthquakes | Little understanding of the locations | Mantle is liquid/magma | / | Formatted |
| and the | of earthquakes | Thickness of Earth layers incorrect | - Ì | Formatted |
| structure of the Earth | Little understanding of the causes of | Mantle is semi-liquid/semi-solid | | Formatted |
| | earthquakes | | | |
| | Poor knowledge of the structure of the Earth and of the state (solid, | | 1 | Formatted |
| | liquid, etc.) of its layers | | | Formatted |
| Plate | Poor understanding of the nature of | Plates made of crust | / | Formatted |
| tectonics | continents and oceans | Many single instances of misconception | | Formatted |
| | Little understanding of the concept | | | Formatted |
| | of 'tectonic plate' | | / | |
| | Poor knowledge of the links | | 1 | Formatted |
| | between earthquakes, volcanoes | | | Formatted |
| | and plate movement | | / } | Formatted |
| History of | None found | Wegener proposed plate tectonics | // | Formatted |
| geology | | | [/] | Formatted |
| Economic | Thinking that oil formed from dead | Oil formed from animals | | |
| geology | sea creatures | Oil formed millions of years ago | 1 | Formatted |
| | Indicating that oil is trapped in [largish] holes under the ground | Misunderstanding of 'ore' | | Formatted |
| | | How traps are formed | · | Formatted |
| Atmosphere | Thinking that the hole in the azone | Geothermal energy is renewable | | Formatted |
| Atmosphere and ocean | <u>Thinking that the hole in the ozone</u> layer results in global warming | Gases are acidic Incomplete carbon cycle | | Formatted |
| | Little understanding of the link | | | |
| | between fossil fuels and the carbon | | $\langle \rangle \rangle^{1}$ | Formatted |
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| CO ₂ in global warming |
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| 4 5 6 7 8 9 10 11 12 13 | Meadows & Wiesenmayer (1999) ide schoolchildren as, 'the "hole" in the o sunlight which results in raising the te (p236). This misconception is also he (elementary) teachers, as noted in a (2000), and in the UK practising prim Meanwhile, Khalid (2003) reports a h US pre-service secondary (high) sch | zone layer allows a g emperature of the ear eld by many pre-servi review of the literatur ary (elementary) teac igh frequency of this | reater penetration of th [global warming].' ce primary e by Summers et al chers they surveyed. |
| 14 | Page 16: [2] Deleted | Chris | 10/28/2008 11:42:00 AM |
| 15 16 17 18 19 20 21 22 23 24 25 26 27 28 | Summers et al (2000) also probed un practising UK primary (elementary) te carbon in fossil fuels was understood most did not grasp the idea that large released into the atmosphere by the researching understanding of the gre teachers were aware of how the atmo- how human activities can enhance th 'striking featureswere practising uncertainty about, the role of carb Page 16: [3] Deleted | eachers, finding that t l by less than half the e quantities of 'ancien burning of fossil fuels enhouse effect show osphere causes the g is. In Summers et al g primary teachers' lo | he 'locking up' of teachers and that it carbon' are being 5. Their work on ed that few of the greenhouse effect or (2001), they report, w awareness of, or |
| 20 29 30 31 32 33 34 35 | Khalid's (2003) work, using the meth US pre-service secondary (high) sch misconceptions about the environme effect, ozone and acid rain. He also r Subbarani (1991) indicating that prac misconceptions. | ool teachers surveyed nt, concerning in part eported the work of H | d held a range of icular, the greenhouse looper (1988) and |
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| 37 38 39 40 | Thus it is surprising that the number atmosphere and ocean in the textboo in some other areas of earth science | | |
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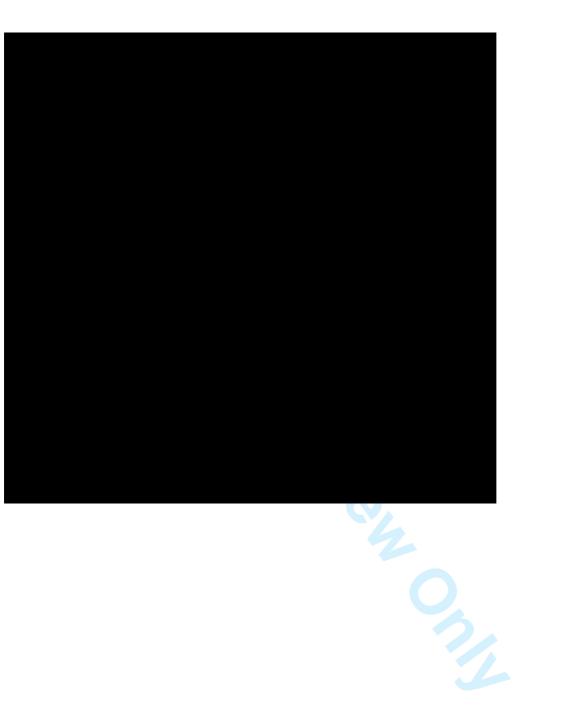
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Figure 1. Instances of earth science misconception in published science materials for 11 - 16 year olds (n = 531).



AN ANALYSIS OF MISCONCEPTIONS IN SCIENCE TEXTBOOKS: EARTH SCIENCE IN ENGLAND AND WALES

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| Criterion | Mean findings of the 27 textbooks for 11-14 year olds | Mean findings of the 24 textbooks for 14-16 year olds | Mean findings from the 51 textbooks surveyed in total | Formatted: No underline, color: Auto |
| Percentage of the National | 52% | 57% | | Formatted: No underline, color: Auto |
| Curriculum earth science statements inadequately covered | | | | Formatted: No underline, color: Auto |
| Percentage of earth science (number of pages of earth science | 8.7% | 10.0% | 9.4% | Formatted: No underline, color: Auto |
| relative to the number of pages in the textbook) | | | | Formatted: No underline, color: Auto |
| Mean number of 'Errors/ misconceptions' per page | 1.1 | 0.9 | 1.0 | Formatted: No underline, color: Auto |
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<u>[... [55]</u>

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| | | | | | | 111 | Formatted |
|--------------------------|------|------------------------------------|---------------------------------|--|-----------------------|---|----------------|
| | | | | | | | Formatted |
| 'semi- | | | in solid state | flow very slowly. | | 11 11 | |
| solid') | | | creep.' | However, the mantle | | 1 1 1 | Formatted |
| | | | (Hancock & | beneath can also flow, | | $-\frac{\eta}{h}$ | Formatted |
| | | | Skinner, 2000, | even though it is | | $1 \neq -\frac{16}{16}$ | Formatted |
| | | | p47) | completely solid. A good | | f = 16 | Formatted |
| | | | 'This view, that the crust is a | _ analogy_is_ice_that, | | - 199 | Formatted |
| | | | relatively thin | capable of being broken | | $i_{\eta_{ll}}^{\eta_{ll}}$ | <u> </u> |
| | | | layer of solid | by a hammer) can flow | | I_{η_0} | Formatted |
| | | | rock on a | downhill in glaciers. | | $-\frac{1}{1}\frac{\eta_{1}}{\eta_{1}}$ | Formatted |
| | | | liquid interior, | When it is near its | | $-\frac{1}{1}\frac{\eta_{1}^{2}\eta_{1}}{\eta_{1}}$ | Formatted |
| | | | became widely | melting point it can flow | | | Formatted |
| | | | prevalent until | more easily. | | | Formatted |
| | | | about a | | | -1.661 | |
| | | | century ago, | | | $(N_{i})_{ij}$ | Formatted |
| | | | when it was | | | 18194 | Formatted |
| | | | shown to be | | | 1.669 | Formatted |
| | | | unsound.' (Duff, 1993, | | | 1388 | Formatted |
| | | | (Dull, 1993, p12) | | | 1822 | <u> </u> |
| C. Plates | 25 | Plates can be | 'Plate. A | The tectonic plates are | Thinking | 「聽的 | Formatted |
| incorrectl | 4.7% | made from | segment of the | | that leaves | 1883 | Formatted |
| y | · ′ | oceanic or | lithosphere | lithosphere around 100 | are made of | 1888 | Formatted |
| described | | continental crust | which is | km thick. They overlie | a layer of | 1942 | Formatted |
| as made | | (L8 – 106 – a | bounded by | | palisade | | Formatted |
| of crust. | | chemistry | plate margins' | | cells only. | | <u>}</u> |
| eg. | | textbook for 14 - | (Allaby & | which flows slowly, | | | Formatted |
| 'plates | | 16 year olds) | Allaby, 1991, | moving the plates - thus | | 0"// | Formatted |
| are made | | the Earth's crust consists of a | p284) | there is a physical boundary between the | | 11/1 | Formatted |
| of crust' or 'crustal | | number of pieces | Lithosphere. | solid lithosphere and the | | 1111 | Formatted |
| plates' | | called plates' | | ductile asthenosphere | | | Formatted |
| platee | | (L3 – 34 – an | continental) | (the 1300°C isotherm). | | | |
| | | examination | layer of the | The lithosphere | | $1 \neq j_i$ | Formatted |
| | | syllabus for 14 – | solid Earth, | comprises the crust and | | i = ii | Formatted |
| | | 16 year olds) | comprising all | the uppermost mantle, | | -74 | Formatted |
| | | | crustal rocks | which are chemically | | -119 | Formatted |
| | | | and the brittle | different but both | | 114 | Formatted |
| | | | part of the | physically solid and | | 1141 | |
| | | | uppermost mantle. | rigid. The crust is around 7 km thick in | | 1140 | Formatted |
| | | | (Allaby & | oceanic areas and | | 1.677 | Formatted |
| | | | Allaby, 1991, | averages 35 km thick in | | $\frac{1}{1} \frac{\eta_{11}}{\eta_{11}}$ | Formatted |
| | | | p219) | continental areas - | | | Deleted: alone |
| | | | . / | much thinner than the | | N// | Formatted |
| | | | | lithosphere. | | N/// | |
| .D. | 23 | Layers of | Lithification. | Most sedimentary rocks | Considering | | Formatted |
| Indicating | 4.3% | sediment form | The process of | cannot be formed by | that plants | 11/1 | Formatted |
| that | | sedimentary rock | changing | compaction alone: some | need only a | | Formatted |
| sediment | | when put under | unconsolidate | 'cementation' is required | source of | 11/2 | Formatted |
| ary rocks | | great pressure. | d sediment | to 'glue' the grains | light to | ¥ | Formatted |
| are formed | | (L14 – B2, 95 – textbook series | into rock. This involves | together. Fluids flowing through the pore spaces | photo- synthesise. | -<[] | <u> </u> |
| by | | for 11 -14 year | cementation | deposit natural mineral | synthesise. | | Formatted |
| compress | | olds) | of the | 'cement', Only fine- | | 1.11 | Formatted |
| ion only, | | The rocks made | grains, but not | grained sediment such | | t | Formatted |
| eg. | | when sediments | necessarily | as mud can be changed | | | Formatted |
| 'sediment | | settle under | compaction.' | into sedimentary rocks | | | <u> </u> |
| ary rocks | | pressure are | (Allaby & | like mudstone or shale | | | Formatted |
| are | | called | Allaby, 1991, | by the compression of | | N 18 | Formatted |

| formed | | sedimentary | p218) | the overlying rocks | | 1 | Formatted | [[6 |
|-------------------------|------|--------------------------------------|------------------------------|---|-------------------------|-------------|-----------|----------|
| when | | rocks.' (C5 - B1, | | _ alone, sandstones and | | 1 - J | Formatted | [6 |
| sediment | | 111 - textbook | | _ limestones need | | · | Formatted | |
| s are | | series for 14 – 16 | | cementation. | | | | ([6 |
| compress | | year olds) | | | | , | Formatted | [6 |
| ed by the mass of | | | | | | 1 | Formatted | [[7 |
| the | | | | | | 11 | Formatted | [7 |
| overlying | | | | | | 111 | Formatted | |
| materials' | | | | | | Mil. | | ([7 |
| E. Oil | .14 | Crude oil is made | Oil and gas | Oil and some natural | Thinking | NI - | Formatted | ([7 |
| described | 2.6% | from the | are derived | gas are formed as | that plastics | | Formatted | [[] |
| as | | decomposition of | almost entirely | microscopic plankton | are made | | Formatted | [7 |
| forming | | the bodies of the | from decayed | become buried and | from coal | | Formatted | ···· [] |
| from | | same sea | plants and | heated in the Earth's | | 11 | | |
| animals, | | creatures whose | bacteria.' | crust. The oil-producing | | | Formatted | ([7 |
| eg. <u>'oil</u> | | shells and | (Clark et al. | plankton is mostly | | | Formatted | [[2 |
| and gas | | skeletons make | 1997, p2). | microscopic plants. Most | | 1 | Formatted | [[7 |
| formed | | up limestone. | Source rocks | natural gas is formed as | | / | Formatted | |
| from | | (O1 – B2, 90 – | for oil and gas | buried land vegetation | | × | | [8 |
| dead sea | | textbook series | are usually | becomes coal | | | Formatted | [8 |
| creatures' | | for_1114 year olds) | _fine-grained | | | 1. I. | Formatted | [8 |
| implying | | When these | rich in organic | | | | Formatted | [8 |
| the | | creatures died | matter derived | | | | Formatted | [8 |
| remains | | partial | from bacterial | | | | | |
| of fish | | decomposition of | and chemical | | | - N. | Formatted | ([8 |
| and other | | the remains | alteration of | | | | Formatted | [8 |
| large | | produced crude | algae, bacteria | | | | Formatted | [8 |
| animals) | | oil and the natural | or land plants. | | | | Formatted | |
| , | | gas associated | Organic | | | 11 | | [8 |
| | | with it.' (L15, 140 | sediments, | | | 111 | Formatted | [١ |
| | | revision guide | such as coals, | | | 11 | Formatted | [9 |
| | | for 16 year olds) | can also act as | | | 11 | Formatted | [|
| | | | source rocks, | | | 14 | Formatted | |
| | | | principally for | | | 1 47 | | <u> </u> |
| | | | natural gas' | | | | Formatted | [|
| | | | (Hancock & | | | 111 | Formatted | [[|
| | | | Skinner, 2000, | | | Mill | Formatted | [9 |
| | | faadimaat | p810) | Sodimonto ara not anlu | Considering | Mirin . | Formatted | |
| F. | 11 | <u>'sediment =</u> Particles that | 'Sediments are accumulations | Sediments are not only | Considering | | | <u> </u> |
| Incorrect definition | 2.1% | settle out from a | that were | _ deposited in water, but can be deposited by | that plants = trees and | 1 | Formatted | ([9 |
| s of | | suspension.' (C2 | deposited in | gravity, wind or melting | flowers | 11 | Formatted | [9 |
| sediment | | – BII, 151 – | layers from a | ice. They are | nowers | 1 | Formatted | [] |
| ary | | textbook series | fluid (water or | transported in fluids | | , <u> </u> | Formatted | |
| terms, | | for 11 - 14 year | air) at the | (water or air) by rolling, | | 1 | | ([1 |
| eg. | | olds) | Earth's | sliding, bouncing or in | | 11 | Formatted | ([10 |
| 'sediment | | Understand that | surface. | suspension and are | | | Formatted | [10 |
| is just | | weathering of | (Hancock & | deposited when the | | 57 | Formatted | [10 |
| particles | | rocks can | Skinner, 2000, | energy of the | | <u>``</u> . | Formatted | |
| that settle | | produce particles | p944) | transporting medium | | | | [1 |
| out of | | of rock which can | Weathering. | falls. | | | Formatted | ([1 |
| water' | | settle out from | The group of | Weathering involves a | | | Formatted | [1 |
| and | | rivers as | processes, | range of processes that | | · · · · | Formatted | [1 |
| there are | | sediments e.g. | such as the | usually act together. | | | Formatted | |
| just two | | limestone, | chemical | Several different | | | | ([1 |
| sorts of | | mudstone, rock | action of | physical, biological and | | 1 | Formatted | [10 |
| physical | | salt.' (L3 – 33 – | rainwater and | chemical weathering | | 4 | Formatted | [1] |
| weatherin | | science | of plants and | processes are involved. | | 1240 | Formatted | <u></u> |

| g'or | examination | bacteria and | | | | Formatted: No un | derline |
|------------------------|----------------------------------|--------------------------------|---|--------------------|---------------------------------|---------------------------------|--------------------|
| 'there are just two | syllabus for 16 year olds) | the mechanical | | | | Formatted: No un | derline |
| sorts of | year olds) | action of | | | | Formatted: No un | derline, Fon |
| chemical | | changes of | | | i | color: Auto | |
| weatherin | | temperature, | | | 1 | Formatted: No un | derline |
| g' | | whereby rocks | | | $= \frac{1}{I}i$ | Formatted: No un | derline, Font |
| | | on exposure to | | | $-\frac{1}{1}$ | color: Auto | |
| | | the weather | | | $-\frac{i}{i}\frac{\eta}{\eta}$ | Formatted: No un | derline, Font |
| | | change in character, | | | | color: Auto | |
| | | decay and | | | 147 | Formatted: No un | derline, Font |
| | | finally crumble | | | | color: Auto | |
| | | into soil' (AGI, | | | | Formatted: No une | derline, Font |
| | | 1962, p536) | | | 11 | color: Auto | |
| G. | 10 <u>'Metamorphic</u> : | 'Regional | Widespread (regional) | Thinking | 1 | Formatted: No un | derline, Font |
| Indicating | 1.9% Some igneous | metamorphism | metamorphism that | that water | | color: Auto | |
| that | and sedimentary | . The | produces slates, schists | can boil at | | Formatted: No un | derline, Font |
| metamor phism is | rocks may be buried. Heat and | recrystallisatio n of pre- | and gneisses requires regimes of very high | 50 °C at normal | | color: Auto | |
| caused | pressure change | existing rocks | compression and | (atmospheri | | Formatted: No un | derline, Font |
| by | these rocks. This | in response to | heating These | c) pressures | | color: Auto | |
| overburd | change makes | simultaneous | conditions only occur | -, 1 | 1 | Formatted: No un color: Auto | derline, Font |
| en | metamorphic | changes of | when plates collide. | | 1 | | |
| pressure, | rocks.' (N3 - B9, | temperature, | There is normally not | | (| Formatted: No un color: Auto | derline, Font |
| eg. | 38 – textbook | lithostatic | enough compression or | | | Formatted: No un | dorlino Font |
| 'metamor phism is | series for 11 – 14 year olds) | pressure and,in many cases, | heating produced by burial alone to cause | | | color: Auto | Jennie, i on |
| caused | Metamorphic | shear stress, | metamorphism. | | 100 | Formatted: No un | derline Font |
| when | rocks as those | occurring in | Meanwhile, baking by | | $\langle \cdot \rangle$ | color: Auto | actime, rond |
| rocks are | formed from rocks | • | hot igneous intrusions | | | Formatted: No un | derline, Font |
| buried | which became | where | can cause localised | | | color: Auto | , - |
| and | buried deep | lithospheric | metamorphism. | | Ì | Formatted: No un | derline, Font |
| heated' | underground' | plates are | | | | color: Auto | |
| or 'metamor | S1/2 – 50 – | converging' (Allaby & | | | | Formatted | |
| phic | examination | Allaby, 1991, | | | | Formatted | (|
| rocks are | syllabus for 16 | p311) | | | ANY. | Formatted | [|
| formed | year olds) | Contact | | | | Formatted | |
| by the | | metamorphism | | | | | |
| pressure | | . The | | | | Formatted | (|
| of the | | recrystallisatio n of rocks | | | N. | Formatted: No un | derline |
| overlying rocks and | | surrounding an | | | | Formatted | |
| heat' | | igneous | | | | Formatted | (|
| | | intrusion in | | | / | Formatted: No un | |
| | | response to | | | 11 | Formatted | |
| | | the heat | | | 14 | / | (|
| | | supplied by | | | 1 11 | Formatted | (|
| | | the intrusion. | | | 11 | Formatted | |
| | | (Allaby & Allaby, 1991, | | | 111 | Formatted | (|
| | | p83) | | | Mill | Formatted | (|
| H. The | 10 'The rock surface | The thickness | The crust comprises the | Thinking | | Formatted | [|
| thickness | 1.9% of the Earth is at | of the | continental crust and the | that skin is | [| Formatted | _ |
| es of | most 10 | lithosphere | oceanic crust, with a | 0.1 mm | | | <u> (</u> |
| Earth | kilometres thick. | varies | mean thickness of | thick (skin | 11 | Formatted | (|
| layers are | (H2 - BB, 130 – | between about | around 18 km. The crust | actually | 11 | Formatted | (|
| given or | textbook series | 80 – <u>125 km</u> , | is chemically different | averages 1 | 1.1 | Formatted | (|
| shown | for 11 – 14 year | compared with | from the mantle so the | - 2 mm | 1 2 1 | | |

International Journal of Science Education

| incorrectl | olds) | an average | boundary, the Moho, is | thick) | Formatted | [[130] |
|------------------------|---|---------------------------------------|---|--|-----------|---------|
| У | Crust At its thickest it is about | crustal | a chemical boundary. | | Formatted | [131] |
| | 40km.' (H4 – 166 | thickness of 35 km for the | This boundary does not influence plate tectonics. | | Formatted | [[132] |
| | - textbook for 14 | continents and | The tectonic plates are | | Formatted | |
| | – 16 year olds) | 7 km for the | of lithosphere, | < | | [133] |
| | Earth cross- | oceans' | comprising the crust and | · · · · · · · · · · · · · · · · · · · | Formatted | [[134] |
| | section diagram | (Duff, 1993, | the outermost mantle | <u>`</u> | Formatted | ([135] |
| | showing the core | p599) | and are around 100 km | | Formatted | [[136] |
| | too small and the crust far too thick. | 'Continental | thick. The lithosphere is solid and rigid and the | | Formatted | [137] |
| | C1 - C 147 - | crust averaging | boundary between it and | | Formatted | [[138] |
| | textbook for 14 – | 35km and | the asthenosphere | | Formatted | [139] |
| | 16 year olds) | reaching 70 | beneath is the 1300°C | | Formatted | |
| | , , | km in some | isotherm. The | | | ([140] |
| | | places.' (Duff, | asthenosphere is the | | Formatted | [[141] |
| | | 1993, p14) | 'weak sphere' of the | | Formatted | [[142] |
| | | The boundary | Earth and, although 95 - | | Formatted | [[143] |
| | | [of the core] with the | 99% solid, is able to | | Formatted | [[144] |
| | | mantle lies at | flow, affecting plate movement. The base of | | Formatted | |
| | | a depth of | the asthenosphere is | | | [145] |
| | | c2900 km from | about 350km down. The | | Formatted | ([146] |
| | | the surface | mantle continues down | | Formatted | [[147] |
| | | and the core | to the core/mantle | | Formatted | [148] |
| | | therefore | boundary at 2891 km | | Formatted | [149] |
| | | occupies over 50 percent of the | depth, a boundary between the solid mantle and the liquid | | Formatted | |
| | | | | | | ([150] |
| | | | | ĺ. | Formatted | ([151] |
| | | radius.' (Duff, | outer iron-rich core that is both mechanical and | | Formatted | [[152] |
| | | 1993, p13) | chemical. The | | Formatted | [153] |
| | | | mechanical boundary | | Formatted | [154] |
| | | | between the liquid outer | | Formatted | |
| | | | core and solid inner core | | | ([155] |
| | | | is at 5149 km depth. | | Formatted | [156] |
| | | | The centre of the Earth | Ň | Formatted | [157] |
| | (D. 1 | <u>(0 4 · · ·)</u> | is 6371 km deep. | | Formatted | [[158] |
| I. 10 Misunder 1.9% | 'Rocks containing | Ore. A mineral | The minerals that make | Considering | Formatted | [159] |
| Misunder 1.9% standing | compounds are | or_rock_that can be worked | up most rocks contain metal compounds, but | that_a_coal | Formatted | [[160] |
| of 'ore' | called ores.' (C3 - | economically' | are not ores. The term | thick is a | Formatted | |
| eg. 'rocks | B2, 124 – | (Allaby & | 'ore' has an economic | useful | | [161] |
| containin | textbook series | Allaby, 1991, | context. A rock or | energy | Formatted | ([162] |
| g metals | for 11 – 14 year | p261) | mineral deposit is only | resource | Formatted | [[163] |
| are called | olds) | | an ore if it is rich enough | | Formatted | [164] |
| ores' | Ores are | | for potential commercial | | Formatted | [[165] |
| | mixtures of rocks | | exploitation. | / | Formatted | [[166] |
| | and minerals.' (C5 - B1, 104 | | | ······································ | Formatted | |
| | textbook series | | | | i ! | [167] |
| | for 14 – 16 year | | | j i | Formatted | ([168] |
| | olds) | | | | Formatted | [169] |
| J. 9 | In cold weather | 'Water | Freezing alone does not | Thinking | Formatted | [[170] |
| Misunder 1.7% | | expends on | cause physical | that a plant | Formatted | [[171] |
| standing | and expands. The | freezing, and | weathering of rocks; | will die if | Formatted | |
| of | forces generated | through | many cycles of freezing | you forget to | | [[172] |
| freeze/th | by the ice cause pieces of rock to | repeated alternations of | and thawing are necessary. During each | water it for | Formatted | [173] |
| aw | snap off.' (J1 – | frost and thaw | thaw, water penetrates | one day. | Formatted | [174] |
| process, | 311ap 011. (01 – | nost and that | maw, water perietrates | | Formatted | [175] |

Page 69 of 130

International Journal of Science Education

| eg. 'rocks | C100 – textbook | in water-filled | _ more deeply into the | | | Formatted: No underline |
|---------------|---------------------|------------------------------|-----------------------------------|---------------|-----------|---|
| are | series for 11 -14 | pores and | crack widened by the | | 22 | Formatted: No underline, Font |
| broken by | year olds) | cracks, the | previous freeze, until a | | 100 | color: Auto |
| freezing' | 'Rocks are | rocks are | fragment eventually | | - N. | Formatted: No underline Font |
| | weathered by the | relentlessly | breaks off. | | \sim | Formatted: No underline, Font color: Auto |
| | freezing of water | broken to bits' | The expansion of water | | - N. | |
| | ' (B5 – 96 – | (Duff, 1993, | on freezing, causing this | | N | Formatted: No underline, Font |
| | revision guide for | p22) | process, can be | | N.S. | color: Auto |
| | 14 year olds) | • • | demonstrated by | | 811 | Formatted: No underline, Font |
| | • • | | freezing a sealed | | 19. N. | color: Auto |
| | | | syringe of 10 ml of | | 10 | Formatted: No underline, Font |
| | | | water, (Williams, 1984). | | 1.1 | color: Auto |
| K. 9 | Limestone is a | Limestones | Limestones occur in a | Thinking | - 11 | Earmatted: No underline East |
| Misunder 1.7% | grey rock with a | exhibit the | wide variety of textures | that Iron and | | Formatted: No underline, Font color: Auto |
| standings | rough powdery | same variety | and colours. Some are | steel are | | |
| of | texture. J1 – C99 | of grain sizes, | soft and porous, others | different | Ne. 1 | Formatted: No underline, Font |
| limestone | - textbook series | textures and | are harder and at hand | metals - | illin - i | color: Auto |
| and | for 11 – 14 year | sedimentary | specimen scale are non- | and steel is | 365 | Formatted: No underline, Font |
| chalk, eg. | olds) | | porous (but can be | mainly | 1963. | color: Auto |
| | Chalk: A soft | structures as siliclastic | porous (but can be | carbon | 周辺の | Formatted: No underline |
| 'limeston | | | | CalDUII | 胞的 | |
| e only | crumbly rock | deposits | because of cracks and | | 通路 | Formatted: No underline, Font |
| has grey | composed of the | [conglomerate | fissures). Challe is a type of | | | color: Auto |
| porous | calcium carbonate | s, sandstones, | Chalk is a type of | | 出追 | Formatted: No underline, Font |
| forms' or | shells of | mudstones, | _ limestone_formed_mainly_ | | 通道 | color: Auto |
| chalk is | prehistoric sea | etc.] and, in | _ of the microscopic | | 68 B. | Formatted: No underline, Font |
| made of | animals. H2 - BB, | addition, | plates of planktonic | | | color: Auto |
| the | 93 – textbook | others not | _ single celled plants (ie | | 的比 | Formatted: No underline, Font |
| skeletons | series for 11 - 14 | exhibited by | they are microscopic | | | color: Auto |
| of sea | year olds) | siliclastic | plant remains) | | 144 | Formattade No underline Font |
| creatures' | Chalk is one form | deposits. | | | 出行日 | Formatted: No underline, Font color: Auto |
| | of calcium | (Hancock & | | | 節間 | l |
| | carbonate | Skinner, 2000, | | | 能说 | Formatted: No underline, Font |
| | Limestone is the | p605) | | | 题范 | color: Auto |
| | most important | 'The | | | 福田 | Formatted: No underline, Font |
| | form of calcium | Cretaceous | | | 撤销 | color: Auto |
| | carbonate The | chalks are | | | 动院 | Formatted: No underline, Font |
| | third form of | composed | | | 말했는 | color: Auto |
| | calcium carbonate | largely of | | | 可愿后 | Formatted: No underline, Font |
| | is marble.' N4 - C, | coccoliths | | | 報告 | color: Auto |
| | 121 – textbook | (Tucker, 1982, | | | 出版 | <u></u> |
| | series for 14 -16 | p155) | | | 词题 | Formatted: No underline |
| | year olds) | Coccolithopho | | | 出版 | Formatted: No underline, Font |
| | j | rids are | | | うない | color: Auto |
| | | planktonic | | | 이 집안 | Formatted: No underline, Font |
| | | algae which | | | 通常 | color: Auto |
| | | have a | | | 出的 | l <u>></u> |
| | | skeleton | | | 通過 | Formatted: No underline |
| | | composed of | | | 過盟 | Formatted: No underline |
| | | numerous | | | 一時間 | Formatted: No underline, Font |
| | | calcareous | | | 一词出 | color: Auto |
| | | plates called | | | - 59 | l |
| | | | | | 10.0 | Formatted: No underline, Font color: Auto |
| | | coccoliths. | | | | <u></u> |
| | | (Tucker 1982, p111) | | | | Formatted: No underline, Font color: Auto |
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| Indicating 1.7% that the | | quid' section abov | ve | | | Formatted: No underline |
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| | | | | | | Formatted: No underline, Font color: Auto |
| mantle is semi- | | | | | | Formatted: No underline |
| liquid or | | | | | | Formatted: No underline |
| semi- | | | | | | Formatted: No underline |
| solid M. 8 | Olivine is a hard, | 'A mineral can | A mineral is an element | Confusing | · `` | Formatted: No underline, Font |
| M8 Vineral/r1.5% | dense rock | be defined as | or compound. Thus a | mixtures | 13 - J | color: Auto |
| ock | Olivine is an | a naturally | mineral has a definite | and | | Formatted: No underline |
| confusion eg. | example of a silicate rock | occurring homogenous | chemical composition, atomic structure and | compounds (eg. a | | Formatted: No underline, Fon color: Auto |
| 'mineral' and 'rock' | Olivine is an example of an | solid, inorganically | physical properties (that vary between fixed | mixture of iron filings | | Formatted: No underline, Fon color: Auto |
| mean the same' | igneous rock Olivine and | formed, with a definite | limits). A rock is a mixture of one or more | and sulphur with iron | | Formatted: No underline, Font |
| | similar minerals are sometimes found' (L4 – 11 | chemical composition or | minerals (or fragments of rocks or fossils) so the compositions and | sulphide) | | color: Auto |
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| | - question in a science | range of | structures of most rocks can be very variable. | | | Formatted: No underline, Font color: Auto |
| | examination for 16 year olds) | composition, and an ordered atomic | However, some rocks are formed of | | | Formatted: No underline, Fon color: Auto |
| | 'Some minerals, | arrangement. | predominantly one | | | Formatted: No underline |
| | like limestone, are | (Hancock & | mineral, such as | | | Formatted: No underline |
| | found in rocks on | Skinner, 2000, p692) | limestone (largely | | 199 | Formatted: No underline |
| | their own.' L8 – 47 – textbook for | (Rock. A | _ calcite), quartzite (largely quartz) and rock | | 13.25 | Formatted: No underline |
| | 14 – 16 year olds) | consolidated or | salt (largely halite). Igneous rocks usually | | | Formatted: No underline, Fon color: Auto |
| | | unconsolidate d aggregate of | contain more than one mineral. | | | Formatted: No underline, Fon color: Auto |
| | | minerals or organic matter. The minerals | | | | Formatted: No underline, Fon color: Auto |
| | | may be all of one type or | | | | Formatted: No underline, Fon color: Auto |
| | | of many types | | | | Formatted: No underline, Fon color: Auto |
| | | Allaby, 1991, p319) | | | | Formatted: No underline, Fon color: Auto |
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| N. Basalt 8 | <u>'Molten rock</u> | 'Basalt, a dark- | Granite and basalt are | Confusing | | Formatted | |
| and 1.5% | | coloured, fine- | chemically very different | caustic soda | | | [[186]] |
| granite can form | through volcanoes is | grained extrusive | and so cannot change from one to the other. | (sodium hydroxide) | | Formatted | [[187]] |
| from the | called lava. As | igneous rock | When the mantle | with | | Formatted | [188] |
| same | this cools it forms | containing | partially melts, dark | common | 1 | Formatted | [[189]] |
| magma, | a variety of solids | not more than | magma forms. This iron- | salt (sodium | 11 | Formatted | [190] |
| eg. 'a | and these are | 53 wt% SiO ₂ ' | rich, silica-poor magma | chloride) | 11 - 1 | Formatted | |
| single | known as igneous | (Allaby & | produces basalt if it | | 11 | | ([191]) |
| magma | rock one | Allaby, 1991, | cools quickly at the | | 11 1 | Formatted | 〔 [192] 〕 |
| can | example is | 34) | surface or coarse- | | 11 | Formatted | [193] |
| produce | granite.' (L11 – | 'Granite. A | grained gabbro if it cools | | 12 | Formatted | [[194]] |
| granite or | 100 - textbook for | light-coloured, | slowly at depth. When | | | Formatted | |
| basalt' or | 11 – 14 year olds) | coarse grained | the crust partially melts, | | < | | [195] |
| 'granite | Edinburgh Castle | _igneous rock | a paler, silica-rich | | <u>``</u> | Formatted | ([196]) |
| comes | stands on a 'plug' | ' (Allaby & | magma is formed. This | | N.S. | Formatted | [197] |
| from volcanoe | of granite that was once inside a | Allaby, 1991, p164) | is rarely erupted as lava, but can explode as ash | | 111 | Formatted | [[198]] |
| s' | volcano. N4 - C, | Granites are | or pumice. Usually this | | 111 | Formatted | [[199] |
| 5 | 282 – textbook | intrusive | magma crystallises | | | \ | |
| | series for 14 – 16 | igneous rocks | slowly underground to | | $\langle \cdot \rangle \langle \cdot \rangle$ | Formatted | [[200]] |
| | year olds) | that contain | form coarse-grained | | (()) | Formatted | [201] |
| | ,, | large amounts | granite. | | 114 | Formatted | [[202]] |
| | | of silica (SiO ₂)' | 0 | | - NA | Formatted | [[203] |
| | | (Hancock & | | | $\langle \cdot \rangle$ | Formatted | |
| | | Skinner, 2000, | | | | ` | [[204]] |
| | | p464) | | | N. | Formatted | [205] |
| O. Oil 7 | Coal, oil and | In the North | Most of the gas in the | Thinking | | Formatted | [206] |
| indicated 1.3% | | Sea oil | UK was formed from | that | ALC: T | Formatted | [[207]] |
| as | called fossil fuels. | forms at 3 - | coals deposited as | evolution | (m)) | Formatted | |
| forming | They were made | 4.5 km depth, | swamp deposits some | happened | (1,0) | | [[208]] |
| millions | from plants and animals that lived | gas at 4 – 6 km Burial | 300 million years ago. Most of the oil and some | _millions_of | | Formatted | <u> </u> |
| of years ago, eg. | on Earth about | to these | gas were formed from | years ago | (1,0) | Formatted | [210] |
| ioil | 100 million years | depths occurs | algae and bacteria that | | 1.11 | Formatted | [211] |
| formed | ago.' (N3 B7, 42 - | in areas where | settled on the sea floor | | | Formatted | |
| once in | textbook series | the Earth's | around 140 million years | | N, Ni | | [212] |
| geologica | for 11 – 14 year | crust is | ago. These formed | | 1. 1 | Formatted | [213] |
| l time' | olds) | sagging | source rocks that were | | 1.0.1 | Formatted | [214] |
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| | from the remains | processes | to release their oil and | | | Formatted | [[216]] |
| | of organisms | continue today | gas and are still slowly | | 1111 | Formatted | |
| | which lived | ' (Clark et al. | releasing them today. | | 1.11 | ` <u>}</u> | [217] |
| | millions of years | 1997, p3) | | | | Formatted | ([218]) |
| | ago.' (N1/2 - 38 - | | | | (X, Y) | Formatted | [219] |
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| Category | ces relating to earth science misconceptions Key texts | |
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| Minerals, rocks and | Piaget, 1929; Ault, 1984; Happs, 1982, 1985a, 198 | 5b: Hawley, 2002: Dove, |
| fossils | 1996, 1998; Oversby, 1996; Ford, 2003, 2005 | |
| Sedimentary rocks and | Cosgrove & Osborne, 1983; Dove, 1997 | Happs, 1982; |
| processes | *% | Driver et al, 1994b; |
| Igneous rocks and | Lillo, 1994; Dove, 1998; Libarkin et al, 2005; Dahl | Stofflett, 1994; Kusnick, |
| processes | et al, 2005 | 2002; |
| Metamorphic rocks and | None specific to this topic | Blake, 2004; |
| processes | | |
| The rock cycle | Stofflett, 1993; Ford 2003; Kali et al, 2003; Sibley | |
| | et al, 2007 | |
| Geological time, | Ault,1982; Trend, 1998, 2000, 2001; Dodick & Orio | |
| correlation and dating | 2004; Libarkin et al, 2005; Libarkin & Anderson, 20 | |
| Earthquakes and the | Leather, 1987; Schoon, 1992, 1995; Ross & Shuell | , 1993; Lillo, 1994; Sharp |
| structure of the Earth | et al, 1995; Marques & Thompson, 1997a; King, 20 | 00; Tsai, 2001; Libarkin |
| | et al, 2005; Steer et al, 2005; Rutin & Sofer, 2007 | |
| Plate tectonics | Marques & Thompson, 1997b; King, 2000; Libarkin | et al, 2005; Libarkin, |
| | 2006 | |
| History of geology | None specific to this topic | , |
| Economic geology | Leather, 1987 | |
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Sedimentary

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explanatory model

of earthquakes

earthquakes

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Rock hardness

compression only

Igneous definitions

Sedimentary definitions

Freeze-thaw mechanism Chalk/limestone confusion

Granite forms in volcanoes

Metamorphic rocks formed by

overburden pressure and heat

The rock cycle is continuous

Mantle is liquid/magma

Plates made of crust

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or fossils

Weathering/erosion confusion

Formation of sedimentary rocks by

Magma comes only from the mantle

Metamorphic rocks never contain fossils

Rocks dated by radioactivity of 'rocks'

Thickness of Earth layers incorrect

Many single instances of misconception

Wegener proposed plate tectonics

Oil formed millions of years ago

Geothermal energy is renewable

Oil formed from animals

Misunderstanding of 'ore'

Incomplete carbon cycle

How traps are formed

Gases are acidic

Mantle is semi-liquid/semi-solid

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| Table 4. Comparison between earth science misconceptions common in the | | | | |
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| literature and those most frequently found in the textbook/ syllabus surveys. | | | | |
| Category | Misconceptions of children, students | Misconceptions identified in the | | |
| | and teachers commonly cited in | textbook/syllabus surveys in order of | | |
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| | existing literature | frequency | | |
| Minerals, | | | | |
| Minerals, rocks and fossils | existing literature | frequency | | |

Confusion between 'weathering' and

sedimentary rocks were formed by

Erroneous ideas about volcanoes,

originates in the core and that they

only occur in warm climates or on

Metamorphic processes wrongly

associated with metamorphosis in

The rock cycle not understood as an

Most people had poor chronological

understanding of geological events

Little understanding of the locations

Little understanding of the causes of

Poor knowledge of the structure of the Earth and of the state (solid, liquid, etc.) of its layers

Poor understanding of the nature of

Little understanding of the concept

Thinking that oil formed from dead

Indicating that oil is trapped in

[largish] holes under the ground

layer results in global warming

Little understanding of the link between fossil fuels and the carbon

Poor understanding of the role of

Thinking that the hole in the ozone

continents and oceans

Poor knowledge of the links between earthquakes, volcanoes

of 'tectonic plate'

sea creatures

None found

cycle

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and plate movement

Little understanding that

sedimentary processes

including that their magma

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AN ANALYSIS OF MISCONCEPTIONS IN SCIENCE TEXTBOOKS: EARTH SCIENCE IN ENGLAND AND WALES

Running heading: Misconceptions in science textbooks: earth science

ABSTRACT

Surveys of the earth science content of all secondary (high school) science textbooks and related publications used in England and Wales have revealed high levels of error/ misconception. The 29 science textbooks or textbook series surveyed (51 texts in all) showed poor coverage of National Curriculum earth science and contained a mean level of one earth science error/ misconception per page. Science syllabuses and examinations surveyed also showed errors/ misconceptions.

More than 500 instances of misconception were identified through the surveys. These were analysed for frequency, indicating that those areas of the earth science curriculum most prone to misconception are sedimentary processes/ rocks, earthquakes/ Earth's structure, and plate tectonics.

For the fifteen most frequent misconceptions, examples of quotes from the textbooks are given, together with the scientific consensus view, a discussion, and an example of a misconception of similar significance in another area of science.

The misconceptions identified in the surveys are compared with those described in the literature. This indicates that the misconceptions found in college students and pre-service/ practising science teachers are often also found in published materials, and therefore are likely to reinforce the misconceptions in teachers and their students. The analysis may also reflect the prevalence earth science misconceptions in the UK secondary (high school) science teaching population.

The analysis and discussion provides the opportunity for writers of secondary science materials to improve their work on earth science and to provide a platform for improved teaching and learning of earth science in the future.

248 words

Key Words:

earth science education; high school; misconception; secondary school; textbooks.

EARTH SCIENCE IN ENGLAND AND WALES

'Earth science' in the National Curriculum for Science (NCS) in England and Wales covers content that is largely geology-related and so differs from the broader 'earth science' taught through some science curricula in other parts of the world. The 'earth science' in the NCS evolved through four mandatory versions prior to the survey reported below, as described in King (2001). The initial version (DES, 1989) contained 17 sections of content including two directly related to earth science, namely 'Human influences on the Earth' and 'Earth and atmosphere'. During subsequent revisions, the 'Human influences on the Earth' section was incorporated into biological sections, and developed a strong ecological flavour. Meanwhile, the 'atmosphere' section was largely removed and the 'earth' section, comprising largely geological material, was incorporated in the chemical section.

The textbook survey was carried out against the version of the National Science Curriculum based on this <u>model</u>, <u>which</u> was mandatory at the time (QCA, 1999). For 11-14 year olds (Key Stage 3, KS3) this involved: physical and chemical weathering; the formation of sedimentary, igneous and metamorphic rocks; a discussion of different energy sources; and a little on environmental protection. Meanwhile, 14-16 year olds (Key Stage 4, KS4) covered: fossils in the context of evolution; environmental issues; changes in the atmosphere and ocean over time and the carbon cycle; evidence for sedimentary, igneous and metamorphic rock formation and their subsequent deformation; seismological evidence for the Earth's structure; plate tectonics; and the radioactive dating of rocks.

Since the textbook survey was carried out, the National Curriculum for Science has been revised yet again, the section for 14-16 year olds (KS4) in 2004 (DES, 2004) and the section for 11-14 year olds in 2007 (QCA website). In these revisions, the content of the curriculum is presented in a less detailed and prescriptive way, but the earth science has been separated out into a different section again. So the current version has four sections, focussed on biology; chemistry; physics and earth, and environmental science and astronomy. This important development may give scope for the further development of the earth/environmental science content of the curriculum in the future.

In other countries across the globe, 'earth science' often includes much more on the atmosphere and oceans and on environmental change than is covered by the science curriculum in England and Wales (King, 2008a). In England and Wales, this material is usually covered in more detail in the geography curriculum.

Thus, the perspective on 'earth science' taken as the basis for this research is the geology-centred earth science <u>currently</u> studied in secondary (high) schools in England and Wales.

TEXTBOOKS, SYLLABUSES AND EXAMINATIONS IN ENGLAND AND WALES

A survey of all the science textbooks in print and being used in secondary (high) schools in England and Wales was carried out in the Spring of 2002. All the major publishers of science textbooks who exhibited at the Association for Science Education (ASE) Annual Meeting in January 2000, and all the relevant textbooks in print that they published, were covered by the survey. Each contributed between one

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International Journal of Science Education

and five textbooks or series. A total of 13 books or series for 11-14 year old pupils (KS3) was reviewed and 16 books or series for 14-16 year olds (KS4). The total number of individual books surveyed was 27 at KS3 and 24 at KS4, a grand total of 51 books. The full survey was described in a report (King et al, 2002) and in a subsequent publication (King et al, 2005)

The 'errors/ oversimplifications' identified in the textbook survey were added to the similar list derived from a previous survey of syllabuses and examinations for 16 year olds (King et al, report 1998, publication 1999). Following, publication of the textbook report, other sources of earth science information written for 11 – 16 year olds were examined and some publishers invited the authors of the reports to proof-read drafts of textbook material. During these exercises, more examples of 'error/ oversimplification' were identified and added to the list. The final list of 'error/ oversimplification' examples recorded through all these surveys numbered more than 500.

In England and Wales, government control of the content of school science is restricted to publication of the National Curriculum for Science, such as the current example (QCA website), and oversight of the examination processes. This provides freedom for any publisher to produce textbooks or other teaching materials without government scrutiny. Meanwhile the examination processes are managed by commercial organisations called Awarding Bodies (or Exam Boards). The Awarding Bodies produce the syllabuses, which should cover the National Curriculum content, and a government body, the Qualifications and Assessment Authority, approves the syllabuses. The Awarding Bodies produce the examinations to assess each syllabus.

As a result of the freedom available to publishers and Awarding Bodies, a range of different publications and syllabuses (with associated examinations) has become available. However, there is little detailed scrutiny of content, particularly in areas less familiar to many teachers and writers, such as earth science. The result is the wide range of 'errors/ oversimplifications' in textbooks, syllabuses and examinations identified in the surveys.

The scale of this issue in the UK was highlighted recently by a piece on earth science submitted for inclusion on the website of a learned scientific institution. Proof reading found ten 'errors/ oversimplifications' in 328 words (King, 2008b), an average of one error in every 33 words.

The 'errors/ oversimplifications' from the textbook and syllabus/examination surveys have been collated to provide insight into the misunderstandings prevalent in the writers of these materials. These are likely to be indicative of the misconceptions held by many science teachers. The misconceptions are being promulgated through use of the textbooks, syllabuses and examinations that are prone to error.

SCIENCE TEXTBOOKS AND THEIR IMPORTANCE

A review carried out in the late 1990s amongst nearly 150 science teachers teaching earth science in England and Wales (King, 2001) showed that their own educational backgrounds in earth science was poor and that science textbooks were key sources of information for them. These included science textbooks written for 11–14 year olds (25% of responses), science texts written for 14–16 year olds (15%) and

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general science textbooks (29% of respondents). Science textbooks were much more widely used than earth science-specific materials (used by a mean of only 12% of respondents). The only more widely used source of support was their science colleagues (46% of respondents).

This research indicating widespread use of textbooks in the UK is supported by a report of the government Council for Science and Technology (CST, 2000) which found that 89% of the 586 secondary (high) school teachers surveyed used science textbooks 'often' (whilst 39% used their colleagues 'often' as well).

Meanwhile Ball and Cohen (1996), quoting Goodlad (1984), note that 'Commercially published curriculum materials dominate teaching practice in the United States', and continue,

'Unlike frameworks, objectives, assessments and other mechanisms that seek to guide curriculum, instructional materials are concrete and daily. They are the stuff of lessons and units, of what teachers and students do. That centrality affords curricular materials a uniquely intimate connection to teaching' (p6).

Good (1993) says, 'most science teachers seem to use science textbooks most of the time ...' (p619) and Abraham et al. (1992) comment, 'In the experience of the researchers, many junior high school teachers are much too dependent on textbooks.' (p117). Wandershee et al. (1994) in reviewing the claim that 'Teachers often subscribe to the same alternative conceptions as their students', comment, 'In the defence of teachers, the persistence of their alternative conceptions may be an effect of poor college science textbook writing or poorly taught science courses' (p189). Clearly science textbooks have a very important influence on both science teachers and their pupils.

It was for this reason that the American Association for the Advancement of Science, as part of its Project 2061, undertook a review of science textbooks available to teachers in the USA. Their findings have been reported and discussed in a number of reports and publications. In one of these, Kesidou & Roseman, (2002) state that,

"Whereas curriculum materials (and in particular textbooks and their accompanying teacher's guides) are but one of the resources available to teachers, they have a major role in teaching and learning. Many teachers rely on them to provide some or all of their content and pedagogical knowledge, and this is specially so when the teacher is a novice or is teaching outside his or her area of expertise ...' (p522).

Stern & Roseman (2004) add, 'For better or for worse, the majority of schools are still relying on textbooks as the primary source of the classroom curriculum, and textbooks strongly influence student learning through their influence on teachers.' (p556).

The overall findings of the Project 2061 textbook evaluation team were that the textbooks evaluated were generally poor in a number of ways. For example, 'Programs [textbook teaching schemes] only rarely provided students with a sense of purpose for the units of study, took account of student beliefs that interfere with learning, engaged students with relevant criteria to make

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abstract scientific ideas plausible, modelled the use of scientific knowledge so that students could apply what they had learned in everyday situations, or scaffolded student efforts to make meaning of key phenomena and ideas presented in the programs.' (Kesidou & Roseman, 2002, p522),

'currently available curriculum materials provide little support for the attainment of key ideas chosen by this study. In general, these materials do not take into account students' prior knowledge, lack representations to clarify abstract ideas, and are deficient in phenomena that can be explained by the key ideas and hence make them plausible.' (Stern & Roseman 2004, p538), and

'Assessment scores of life and earth sciences are almost uniformly poor' (Stern & Ahlgren, 2002, p897).

Although the research methodology of the Project 2061 researchers has been questioned (Holliday, 2003), it has also been strongly defended (Kesidou & Roseman, 2003).

As part of their work, the Project 2061 evaluation team reviewed the earth science content of middle school science textbooks (for 11 - 14 year olds) published in the USA against eight earth science ideas. Their ratings, as published on the Project 2061 website (AAAS – Project 2061), find the texts examined to be almost universally poor when measured against a range of instructional categories.

This issue is prevalent in other educational systems, as indicated by Sellés-Martinez (2007) for Argentina, in citing examples of the earth science content of seven Spanish introductory science textbooks which, 'rendered alarming results.' (p207).

This review of importance and quality of science textbooks, and particularly their earth science components, provides the backdrop to the surveys carried out in England and Wales.

SURVEY METHODOLOGY THAT IDENTIFIED ERRORS AND OVERSIMPLIFICATIONS

'Errors/ oversimplifications' were first identified in a survey of the GCSE science examination syllabuses in use in England and Wales in 1996. General Certification in Secondary Education (GCSE) syllabuses and examinations are aimed at 16 year olds, which are taken by more than 80% of the school students in the two countries. The survey was undertaken by five experienced earth science teachers and examiners and covered all 11 examinations available in 1996 in England and Wales at the time. The survey covered the syllabuses used and the science examinations set for each of the syllabuses in 1996. Each syllabus and set of examination papers was evaluated independently against a proforma by two members of the working group and their views were combined by a moderator to provide an overview. The findings were reported in King et al. (report 1998, publication 1999). The survey identified poor coverage of the earth science components of the National Curriculum and no syllabuses that were error-free; 13 'errors/ oversimplifications' were recorded. Meanwhile the examinations showed a preponderance of low level, recall-based questions and also contained errors. Three of the eleven sets of papers contained

seven 'errors/ oversimplifications' between them. The draft survey report was sent to all the Awarding Bodies for comment. No feedback was received and so the final report was prepared and widely circulated.

It is noteworthy that a more recent survey of the six GCSE science syllabuses available in England and Wales in 2004 (King et al. 2004) found better National Curriculum coverage and a much reduced 'error/ oversimplification' level. The most recent 2007 survey of the five GCSE science syllabuses (now called specifications) currently used, found a poorer National Curriculum coverage but a further reduction in the level of 'error/ oversimplification' (King and Hughes, report 2007, publication 2008). The reduction in the level of 'error/ oversimplification' over time may reflect publication and dissemination of the results of the previous surveys.

A survey of all the science textbooks in print and in use in schools in England and Wales was undertaken in 2002 to identify a base level of quality of earth science content against which future textbooks could be judged (King et al, report 2002, publication 2005). As indicated above, 13 books or series (programs) for 11–14 year old pupils and 16 books or series for 14–16 year olds were reviewed, involving 27 books for the 11-14 age range and 24 for 14-16 year olds, a total of 51 textbooks.

The survey was carried out by four experienced earth science educators. Initially a proforma similar to that used in the syllabus survey above was agreed, through which each book could be checked for National Curriculum coverage, and percentage of earth science content and any 'errors/ oversimplifications' included would be noted. The recorded 'errors/ oversimplifications' were not simply typing or grammatical errors, but were errors which showed that the author had an incorrect understanding of the process being described. The 'oversimplifications' involved simplifications that had introduced errors. All of the 'errors/ oversimplifications' recorded were re-written correctly at a similar language level and with a similar number of words, to illustrate to the publishers and authors that the material could have been presented correctly.

The proforma was initially applied by all the reviewers to the same textbook and, following discussion at the moderation meeting, the final form of the proforma and methodology was agreed. Each reviewer then reviewed their quota of textbooks and their results were moderated by the coordinator. The complete set of moderated comments was circulated to all involved for further comment and checking before the results were collated. The findings allowed the textbooks to be ranked in terms of National Curriculum coverage, amount of earth science included (percentage of pages of earth science relative to the number of pages of the book), numbers of 'errors/ oversimplifications' and amount of material additional to the National Curriculum content.

Finally, the full 100+ page draft report containing all the data was sent to all the publishers involved for their response, and the limited feedback received was incorporated, before publication and wide circulation of the final report. The report findings are summarised in Table 1.

Table 1 hereabouts. Baseline data obtained from the survey of the earth science content of secondary science textbooks, Spring 2002.

The report findings show that that more than half the National Curriculum earth science content was inadequately covered and that the mean level of 'error/ oversimplification' was one error per page of earth science. Of the 29 textbooks/ series evaluated (several textbooks in the same series were treated together), no textbook/series was completely error-free. The lowest error level was 0.1 error per page of earth science. Seventeen textbooks/series had 0–1 errors per page; nine textbooks/series had 1-2 errors per page and three textbooks/series had more than two errors per page, the worst having 2.5 errors per page (66 'errors/ oversimplifications' in 26 pages). Through the textbook survey, 453 instances of 'error/ oversimplification' in total were recorded.

During 2003, more instances of 'error/ oversimplification' in material published for use by science teachers were identified: 38 from proof-reading of pre-publication science textbook material and 20 from a BBC science revision website.

Together a total of 531 instances of 'error/ oversimplification' was identified from all these sources, and these form the basis of the analysis undertaken below.

EARTH SCIENCE 'ERROR/ OVERSIMPLIFICATION' DATA COLLECTED FROM THE SCIENCE-TEACHING MATERIALS

The 531 instances of 'error/ oversimplification' have been categorised and are shown graphically in Figure 1.

Figure 1 hereabouts. Instances of earth science 'error/ oversimplification' in published science materials for 11 - 16 year olds in England and Wales (n = 531).

Figure 1 indicates that the majority of 'errors/ oversimplifications' relate to rocks and rock-forming processes (40%), particularly to sedimentary rocks and processes (24%). A high percentage is found in the earthquake, Earth's structure and plate tectonic categories (29%), whilst in the data relating to economic geology, more than half (9% of the total) related to energy.

Some 'errors/ oversimplifications' occurred in the data as multiple instances and these have been ranked in order to show those 'errors/ oversimplifications' that are most widespread amongst writers of published science materials. The 'top 15' examples of 'error/ oversimplification' found are ranked in Table 2, each instance comprising more than 1.3% of the data. The table lists:

- the earth science 'error/ oversimplification' as it might be found in a textbook;
- its prevalence in the data;
- examples of quotes containing 'errors/ oversimplifications' taken from the materials reviewed
- the scientific consensus view, given as quotes from authoritative textbooks;
- discussion providing guidance to those attempting to address the 'error/ oversimplification' in question;
- an example of an 'error/ oversimplification' of similar significance in another science area – provided to give some indication to the non-specialist of the 'importance' of the 'error/ oversimplification' to the teaching of earth science.

Table 2 hereabouts. Common earth science 'errors/ oversimplifications' in secondary (11 – 16 year old) science textbooks in England and Wales – in rank order of frequency.

ERRORS/OVERSIMPLIFICATIONS, MISCONCEPTIONS AND ALTERNATIVE CONCEPTIONS

The term 'errors/ oversimplifications' has been used above because of its usage in the two reports King et al. (1998) and King et al. (2002). The term was used independently of any usage of the terms in research literature, specifically for use with sources of information written for teachers and pupils (pupil textbooks, examination syllabuses, etc).

However there has been wide discussion in the literature around the best terminology to use for instances of error and misconception. For example Abimbola, (1988) cites the following usage,

'the kinds of knowledge that researchers consider as 'wrong' knowledge ... [include the following examples] 'errorneous (sic) concepts' ... ; 'misconceptions' .

He goes on to discuss use of the terms 'alternative frameworks' and 'alternative conceptions'. 'Alternative conceptions' is his preferred term, for, 'particular conceptions that are held strongly and persistently by students' (p180).

Wandershee et al, (1994) in their discussion of the 'plethora of terms' used in this field, also decide that 'alternative conceptions' is the most appropriate term for the understandings that children have, whilst noting that 'Not all researchers, however, agree that the term misconception should be disregarded' (p179). Meanwhile Dove (1998) reviews usage of some of the terms noted above, together with, 'children's science', 'preconceptions', 'untutored beliefs', 'intuitive notions', 'ideas' and 'errors' (p184) before also deciding to use the term 'alternative conceptions'.

Much of the discussion of terminology has centred on the ways in which children form ideas about science and the ways in which these ideas are retained, even if they differ from consensus views in science (or 'final form science' - Duschl, 1990) (Driver et al, 1985, 1994b). These can rightly be called 'alternative conceptions' since they are conceptions of the science derived from the experiences of the pupils.

However, the instances observed in textbooks and other similar sources cannot be described as 'alternative conceptions' since, while they may have first developed as a child's evolving view of science, they may well have come from other sources as well, such as erroneous information written elsewhere, or older consensus views, now superseded. They may derive from the author's limited understanding, from poor attempts to simplify ideas for their pupil-readers, or by inadequate attempts to couch their writing to address the views of science that pupils are likely to have, the 'children's science' of Gilbert et al (1982, p623). Where they clearly differ from today's scientific consensus they can best be described as 'errors', however the ways in which they are written in textbooks and their widespread usage indicates that many of these errors are not simple mistakes, but are deep-seated and widely

held amongst the writers, which is why the term 'misconception' will be used for these instances in this paper hereafter.

Research into misconceptions in science education has a long track record, with prominent publications in the 1980s (Gilbert & Watts, 1983; Driver et al, 1985; Gunstone at al, 1988) and the 1990's (Driver et al, 1994a, 1994b, Wandershee et al, 1994). Much of this work has focussed on biology, chemistry, physics and space science; nevertheless, there is a small body of work on misconceptions in earth science, discussed below.

EARTH-SCIENCE MISCONCEPTIONS: COMPARISONS BETWEEN THE LITERATURE AND THE TEXTBOOK/SYLLABUS SURVEY FINDINGS

Little analysis of the misconceptions in the earth science content of published textbooks has been carried out previously. Thus the list of more than 500 misconceptions from the textbook and syllabus surveys has been subjected to analysis to identify those areas of earth science most prone to misconception. This textbook and syllabus data is important, as most textbook and syllabus writers are themselves, or have been, science teachers, so the analysis provides a guide to the misconceptions held more generally by science teachers in England and Wales. Such information on the misconceptions of practicing science teachers is not readily available since most research into earth science misconceptions to date has focussed on primary (elementary) and secondary (high school) pupils, on college students, or on trainee (pre-service) teachers from a range of countries.

A comparison of the textbook/ syllabus analysis with the published earth science misconception work, largely from pupils, students and trainee teachers, has enabled a series of similarities and differences to be identified. The textbook/ syllabus data was categorised into a number of earth science areas and most of them attracted at least some research allowing comparisons to be made.

Key works relating to earth science misconceptions are listed in Table 3 whilst earlier works are summarised in Thompson (1986). The main areas of comparison/ contrast between the research literature and the textbook/ syllabus survey are described below and tabulated in Table 4.

Table 3 hereabouts. Key references relating to earth science misconceptions.

Table 4 hereabouts. Comparison between earth science misconceptions common in the literature and those most frequently found in the textbook/ syllabus surveys.

Minerals, rocks and fossils

The concepts of rocks, minerals and fossils provide key building blocks of geological understanding. However, many pupils bring with them a range of misconceptions about them, as indicated by Happs (1982), 'The term 'rock' is largely used in a non-scientific way ...' (p14) and Dove (1996), 'the [assessment] activities provided ... evidence to suggest that the term 'rock' is widely misunderstood among students' (p269).

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Concerning minerals, Blake (2004) noted that the term 'mineral' was a problematic concept for 9-11 year old children whilst Happs (1982) found no 11-18 year old students that were able to use the term 'mineral' in the scientific sense.' (p18).

Children's understanding of rocks has been studied since Piaget (1929) reported that many young children thought that rocks were created by men or God whilst others thought they grew from seeds in the soil. Studies since have been summarised by Dove (1998, p185) as showing that pupils of all ages regarded rocks as, 'dull, heavy, large, dark material ... [and] colour was also an important criterion'. Children also confuse rocks with minerals (Happs, 1985a; Oversby, 1996). Meanwhile Ford (2003) found that, unlike experienced earth scientists, most primary (elementary) children in his survey (87% in the group studied using a rock kit) looked for properties that provided no evidence of the mode of rock formation. Blake (2004) summarised his work and others as, 'Children's alternative conceptions for describing and classifying rocks centre on simple physical properties such as colour or shape and reveal only limited ideas about the origins of rocks.' (p1857). Meanwhile Happs (1985b) has shown that even when children do make the observations that would allow them to interpret how rocks were formed, they can often misinterpret these clues, and come to incorrect conclusions. Misconceptions about rocks are particularly problematical when children are asked to classify and identify rocks, so it is not surprising that when trainee (pre-service) teachers were asked to teach rock identification, they showed relatively high anxiety levels (Westerback et al, 1985). These studies reveal the need for systems to teach about rock characteristics and classification using intrinsic features that provide evidence of the rock-forming processes, such as that described by Hawley (2002).

Oversby (1996) in researching understanding of fossils, has shown that many pupils and pre-service teachers, when given descriptions of fossils and non-fossils, were unable to distinguish between them. He concluded that, 'A source of the confusion may be that pupils have been taught that a petrified body is an example of a fossil; this is then reinterpreted as a belief that only petrified bodies are fossils.'(p 94). This comment links with two similar examples found in the textbook survey.

The textbook survey showed marked similarities between the misconceptions concerning minerals, rocks and fossils found in textbooks and those described in the literature. Eleven examples of misconceived rock definitions were found in the textbook survey (including confusion between 'minerals' and 'rocks') together with confusion about the meaning of 'hardness' as applied to rocks. Confusion was also found in textbooks around processes of fossilisation, similar to those found by Oversby (1996) who found for example, suggestions that there is only one method of fossilisation. Since textbook writers were once pupils and later were trainee teachers, these similarities are not surprising.

Sedimentary, igneous and metamorphic processes

Research into understanding of rock-forming processes has ranged from broad studies of a range of processes and their rock products to those that focus on specific processes. Dove, in her 1997 survey, investigated student ideas about weathering and erosion and uncovered a range of misconceptions. As Dove (1997, 1998) describes, this is probably because the terms have altered in meaning over time and can still be interpreted in different ways by textbooks of today.

Nevertheless, the definitions are clear in most authoritative texts used by earth scientists, as shown in Table 2.

Many of the misconceptions identified by Dove were also found in the textbook/ syllabus surveys, where confusion between the terms 'weathering' and 'erosion' (Table 2, Section A) provided the greatest incidence of misconception recorded. It is because processes of weathering and erosion generally act together that, if the processes are to be properly understood, they need to be distinguished so that the results of combining different processes in different ways can be interpreted. This fine point may be lost on a non-specialist teacher, which is why a comparable chemical example is added to Table 2 in an attempt to indicate to a non-specialist the scale of the issues involved.

The fact that freeze/ thaw weathering requires many cycles of freezing and thawing (Table 2, J) is not made clear in many science texts. This misconception can be compounded by the findings that many pupils expect water to shrink on freezing, rather than to expand (Cosgrove and Osborne, 1983). They recommend that teachers should demonstrate to pupils that water does expand on freezing, to underpin their correct understanding of the freeze/ thaw weathering process.

The evidence for processes of rock-formation, and the environments in which the rocks formed, is preserved in the rocks. Thus misunderstandings about rock-forming processes will be reflected in misunderstandings about the features preserved in rocks, and vice versa. Happs (1982) found a range of misunderstandings in children about the concepts of sedimentary, igneous and metamorphic rocks such that Driver et al (1994b) summarised his work as, 'Very few children ... appreciated the relationship between sedimentary rocks and the sedimentary processes by which they are formed. ... Most children ..., when confronted with specimens of igneous rocks had no ideas on formation to offer ...' and, '... the word 'metamorphic' was associated by most children with metamorphosis in animals ...' (p113). Misunderstandings like these can be carried right through to adulthood as shown in Stofflett's (1993) work with pre-service primary (elementary) teachers, commenting that, 'The misconceptions exhibited in this study [about rocks and their formation] were, quite frankly, appalling.' (p230). Stofflett (1994) also showed that the, 'average teacher candidate understood only 18 percent of the concepts [relating to rockforming processes] presented.' (p495). Kusnick (2002), in another survey of preservice primary teachers, showed that, 'Students hold a surprising number of misconceptions about how rocks form.' (p31), commenting that, 'a startling number of students described rocks as forming by processes that no geologist would recognise.' (p37) and concluding that, 'students need schooling experiences which build a basis for conceptual understanding ...' (p38).

Ford (2005) researched understanding of the rock cycle as a whole and found that 11-12 year old US pupils, having previously learned about the rock cycle, rarely mentioned it in their explanations of the formation of different types of rocks. She found that,

'students did not grasp the purpose of instruction about the rock cycle. Instead their responses indicate they perceive the rock cycle as the *cause* of rock formation, rather than a model representing relationships between rock categories and their formation. For example, when asked how a rock formed,

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one student responded, "It went through the rock cycle" much as laundry goes through a wash cycle – something that is done to a rock to change it.' (p375).

Meanwhile, Kali et al (2003) have shown that the type of thinking needed to understand the rock cycle and related systems thinking, involves high order thinking skills – but thinking skills that can be developed through appropriate teaching strategies. Meanwhile Sibley et al (2007) have shown that novel approaches (in their case, by asking students to link processes in a 'box diagram') can be effective in teaching cyclic thinking of the type needed to understand the rock cycle.

Work specifically related to the understanding of igneous processes has been reviewed by Dove (1998) who found a, 'tendency for students to confuse earthquake with volcanic activity.' (p187) – going on to stress that, 'only a minority of earthquakes are caused in this way.' (p188). Some studies, such as that of Lillo (1994) and Dahl et al (2005) have shown the misunderstanding that magma that erupts through volcanoes originates in the Earth's core – when virtually all magma is thought to originate in the upper portion of the mantle or crust (Hancock & Skinner, 2000). Researchers have also found that US college students, 'believed that volcanoes only occur on islands, that they are associated with warm climates, and that volcanoes only occur along the equator, among other ideas.' (Libarkin et al, 2005, p24). These findings were supported by Marques (1988) for Portuguese students of ages 10-11 and 14-15.

Given the widespread misconceptions about rock-forming processes found in these studies, it is not surprising that misconceptions were also common in the textbook materials surveyed, with errors around the rock-forming processes forming 40% of the total data: sedimentary – 24.1%; igneous – 7.5%; metamorphic – 8.3%. The misconceptions were wide-ranging and the most common concerned lack of understanding about how sediments become cemented to produce sedimentary rocks (indicating, for example, that sedimentary rocks are formed by compression only), confusion about limestone and chalk formation (eg. chalk is made from skeletons), misunderstandings about sediment and soil (eg. sediment grains are always small), about where magma comes from (suggesting magma comes from the core) and how granites and basalts form, and misconceptions about the causes and results of metamorphism (indicating that metamorphism happens when rocks are buried). Consensus scientific views on these topics are given in Table 2.

Geological time, correlation and dating

Children's understanding of geological time was investigated by Ault (1982) and this work has been followed up more recently by a number of researchers. Schoon (1992, 1995) showed that nearly a third of the US primary (10-11 year old) pupils and a fifth of the pre-service primary teachers in his surveys thought that dinosaurs lived at the same time as cavemen. Trend (1998) studied the understanding of upper primary (10-11 year old) UK pupils showing that although the children had, 'a general awareness of major events such as the Ice Age and moving continents ... a clear chronology is almost entirely lacking.' (p973). Trend went on to study understandings of geological time among UK pre-service primary teachers (2000), concluding that, 'Trainee teachers ... are more comfortable and imaginative with their teaching of history than with their geology, despite the parallels.' (p539). In further commentary, Trend (2001), 'proposed that the nature and quality of UK society's engagement with

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geoscience phenomena is constrained by an all-pervasive confusion with deep time, both relative and absolute.' (p196). He also found that, 'Primary teachers do not have a secure grasp of deep time either in absolute or relative terms.' (p215) indicating that they are neither secure with the magnitude of geological time (the big numbers) or the ordering of time (the relative dating and correlation of geological events). This work is supported by that of Hidalgo and Otero (2004) who showed that students find it difficult to remember timed events in isolation. While they are sometimes able to deduce the order of geological events from other information, they 10 find it very difficult to conceptualise long periods of time. Libarkin et al (2005) found 11 that US college students held a number of misconceptions about the dating of the 12 formation of the Earth and the formation of life. In further work Libarkin & Anderson 13 (2005) found that students had poor ideas of the scale of geological time, the 14 occurrence of events in geological history and absolute age dating. Meanwhile, Dahl 15 et al (2005) working with US practising teachers, found that they were fairly 16 comfortable with relative dating, but not comfortable with allocating dates to 17 geological events. Meanwhile Dodick and Orion (2003) have shown that most Israeli students in their study did not have the cognitive skills to cope with the concept of 18 geological time until they reached the age of 12 or older. 19 20

Together, this research indicates that the population at large does not generally have a 'feel' for geological time and that while younger children have difficulty with both relative time (sequencing events) and absolute time (allocating ages to the events) older people are more able to cope with relative time, but still find the concept of absolute time difficult to comprehend.

For these reasons, it is crucial for science textbook writers to at least provide correct information. Thus it is unfortunate that they are also prone to error in this area, producing both numerical errors (eg. that radiometric dating might show a rock to be 9000 million years old, ie. older than the solar system) and general misunderstandings (for example, by stating that the age of a rock can be determined from the rock type). In future, the best examples of textbook writing in this area will respond to Trend's (2001) recommendation to include, 'a carefully designed deep time framework that comprises a small number of key major geo-events ...' (p192) in their work.

Earthquakes and the structure of the Earth

Leather (1987), through his study of UK children's understanding of earthquakes at different ages, has shown how their misconceptions diminished with age and the scientific view became dominant. So, whilst most 11 year olds thought earthquakes were related to hot countries, were directly related to volcanic activity, and could never occur in Britain, they had mainly lost these views by the age of 17. However, Schoon (1992, 1995) has shown in separate surveys that nearly a third of both US primary pupils (10-11 year olds) and pre-service primary teachers thought incorrectly that Chicago could not be damaged by an earthquake; this misconception therefore did not diminish with age. In Israel, a country prone to earthquakes, 77% of the 12–16 years old students surveyed were unaware that their school was situated in a high risk area (Rutin & Sofer, 2007) and many had little idea of the correct response to a future earthquake.

That many primary children (5–11 year olds) have little understanding of the causes of earthquakes has been supported by the work in the US of Ross & Shuell (1993) and in the UK by Sharp et al (1995). The mythological and supernatural views of the origin of earthquakes held by some pupils in Taiwan have been studied by Tsai (2001).

Lillo (1994) researched 10–15 year old Spanish children's understandings of the internal structure of the Earth by asking them to draw pictures. These showed that, whilst most students thought the Earth was formed of concentric layers, and this view increased with age, many of all ages thought the hot molten core was the source of the magma involved in volcanic eruption. Many students also drew the thicknesses of the layers wrongly, with the crust often much too thick. This paralleled a similar misconception of UK practising science teachers (King, 2000) and US college students (Steer et al, 2005). Steer et al (2005), having identified this misconception, used practical model making and peer group discussion to teach the correct dimensions of the Earth's core, mantle and crust, with a high level of success, as shown by post-course assessment several weeks after completion of the course.

Marques and Thompson (1997a) asked Portuguese students to indicate on a diagram where they thought the densest materials in the Earth would be found, and many of primary age indicated near the South Pole. A significant, but reduced number of older students also showed this misconception.

Research into the understanding of earthquakes and the structure of the Earth by older (college) students and teachers has been limited. However Libarkin et al (2005) have shown that, whilst most of the US college students they surveyed related earthquakes to plate tectonics,

'Alternative explanations for the primary causes of earthquakes included the influence of heat, temperature, climate, weather, people and animals ... gas pressure, gravity, the rotation of the Earth and processes in the Earth's core, "exploding soil" and volcances ...' and the expanding Earth (p23).

They also found that, when questioned about the interior of the Earth, 'almost all students mixed physical state (lithosphere, asthenosphere, mesosphere, inner core, outer core) and chemical boundary (crust, mantle, core) terms, indicating a lack of understanding of the basis of subdividing the Earth's interior.' (p24).

King (2000) surveyed practising UK science teachers and found high levels of misconception about the states (solid, partial solid, partial liquid or liquid) of the different layers of the Earth and of the thickness of the crust. Poor understanding was also shown of how the density of the Earth changes with depth and where <u>earthquakes of different</u> depths are likely to be found.

The misconceptions about earthquakes and Earth's interior held by younger children were generally not found in UK science textbooks. However those misconceptions prevalent in US college students and UK teachers were common in the science textbooks. Confusion about the physical state of Earth layers (such as statements that the mantle is liquid, when it is almost entirely solid) and their thickness (for

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common in both the literature relating to older students and the textbook survey.

Plate tectonics

Margues and Thompson (1997b) researched the misconceptions about plate tectonics held by 16-17 year old Portuguese students after they had been taught about plate tectonics in the classroom. They found that many students had developed little understanding of how continents and oceans form and develop. They also had poor understanding of the term 'plate', of how plates move, or the causes of this movement. Meanwhile King (2000) showed that practising UK science teachers had little understanding of how earthquake and heat flow distributions on Earth were linked to plate tectonics. Libarkin et al (2005) showed that some US college students (mainly 19-20 year olds), 'were unsure about the location of the Earth's tectonic plates, believing them to be somewhere below the surface ...', whilst a few, 'place tectonic plates at the Earth's core or in the atmosphere ...' (p23). Many of the students surveyed, 'were unable to conceive of tectonic plates relative to their own space, and most preferred to disconnect tectonic plates and their movement from the Earth's surface.' (p23), whilst few students connected volcanoes with plate tectonics. Meanwhile Libarkin & Anderson (2005) found that most US college students, 'are exiting courses with a poor understanding of the location of tectonic plates.' (p394) and Libarkin (2006) commented on, 'the fact that most [US] college students would claim that they have learned about gravity or plate tectonics in prior coursework does not mean that they fully understand these phenomena.' (p9).

Most instances of misconception in the textbook/ syllabus surveys related to confusion between the thin crust and the thicker lithosphere that forms the plates, a finding that did not figure strongly in the research literature. However, there were also many single instances of misconception in the textbooks (such as indicating that the continental crust was dragged down in subduction, when it is much too buoyant for this to happen), reflecting the confusion identified in the literature noted above.

History of geology

Only a small number of instances of misconception was identified in the textbook and syllabus surveys for this aspect of the curriculum, and there is also little coverage of misconceptions in this area in the literature.

Economic geology

Leather (1987) asked UK pupils what oil formed from, and found that, 'Dead sea creatures (or animals) ... [was] the most popular idea at all ages, and plants, vegetation, leaves or seaweed ... [comes] a strong second.' (p105), although some pupils thought oil formed from water, and others from coal. Few of the pupils he surveyed had a clear idea of how oil was trapped underground,

'The most popular view was that oil is contained below the sea bed in some sort of hollow, described as pockets, holes, spaces, potholes, gaps, cavities, crannies, pools, ponds, crevices, chambers and caves. This answer was given by 16% of the eleven year olds, 35% of the fourteen year olds and 24% of the seventeen year olds. A less common misconception was that oil collects on the sea bed (14% of eleven year olds)' (p106)

These findings relate closely to the misconceptions about oil noted in the textbook/ syllabus surveys. The textbooks also refer to oil being formed from animals/ creatures (when the consensus view is that almost all oil and gas is derived from plant material and bacteria, see Table 2). The textbook survey identified several confused diagrams and statements about oil/ gas trapping mechanisms that relate to the misconceptions of pupils, noted above.

Atmosphere and ocean

The atmosphere and ocean have limited coverage in the science curriculum of England and Wales and therefore only have limited coverage in the textbooks and syllabuses that relate to the curriculum. Thus, a relatively small number of 'errors/ oversimplifications' was recorded in the surveys (20 in a total of 531 instances, or 4% of the data).

- Since the coverage of the atmosphere and ocean, and particularly concerns about the greenhouse effect and global warming, form a key part of the earth science and environmental science studies of pupils across the globe, research into misconceptions in these areas has been extensive, and too large to cover adequately in this discussion.
- Nevertheless the environmental research literature indicates widespread misconception about environmental issues amongst school students and pre-service and practising science teachers. The textbook instances found by the survey, reflected some of the misconceptions noted in the research, relating particularly to incomplete carbon cycles and global warming diagrams showing the atmosphere reflecting heat.

Even after the limited coverage of the atmosphere and ocean noted above is taken

into account, the level of misconception relating to the atmosphere and ocean identified by the survey was smaller than for other areas of earth science. Thus it does seem that UK textbook-writers are more comfortable with this area of the curriculum than with those areas relating to geological science in particular. The syllabus surveys (King at al, 1998, 2004; King and Hughes, 2007), certainly showed poorer coverage of geological science than 'environmental science' concepts.

DISCUSSION AND CONCLUSIONS

Most of the instances of misconception covered by this analysis were identified through a survey of all the science textbooks that were being used in secondary (high) schools in England and Wales in 2002. The survey compared the content of the textbooks with the requirements of the government National Curriculum for science and found poor coverage. During the survey a total of 453 instances of 'error/ oversimplification' were noted. This poor situation is mirrored in the US where the Project 2061 textbook survey (Kesidou & Roseman, 2002; Stern & Ahlgren, 2002; Stern & Roseman 2004) also reported poor content, particularly for the earth sciences. Sellés-Martinez (2007) has found a similar situation in Spanish textbooks used in Argentina. The situation could be summarised in the terms used by Arthur (1996) of, 'Lies, dam lies and books on geology' (p.289). The limited research evidence shows that in countries where there is a 'free press' (no government control over textbook content), the earth science content of broad science textbooks is poor and prone to misconception. However, the situation can be improved by surveys like



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this. As a result of wide circulation and dissemination of the report, several publishers asked for their materials to be proof-read before publication, and this has continued to today.

That scrutiny of syllabuses and examinations can be effective, is suggested by the reduction in the level of misconception shown by three reports over time (King et al, 1998, 2004; King and Hughes, 2007), following their wide circulation and publication of the findings.

Textbooks play a central role in daily teaching, (as indicated by the research described in the 'Science textbooks and their importance' section above) and it is likely that syllabuses and examination papers play an even more crucial role. The work of Ball and Cohen (1996) has highlighted the importance of curriculum materials in developing the understanding of teachers and in influencing teaching and learning. They comment,

'We know far too little about how written materials might support teachers' learning ...[nevertheless] ... we propose the creation of curricula that would help teachers better enact curriculum in practice ... curriculum materials could offer teachers opportunities to learn in and from their work.' (p8).

The analysis of the misconception data for science textbooks and syllabuses in England and Wales summarised in this paper has revealed the misconceptions that are most prevalent amongst writers of science materials. Misconceptions are particularly common in the areas of sedimentary processes/ rocks, earthquakes/ Earth's structure, and plate tectonics. Study of Earth science misconceptions forms an important part of the research literature in earth science education, summarised by King (2008a).

Comparison between the earth science misconceptions identified in the literature and those noted in the textbook/ syllabus surveys show contrasts for different age levels. Where much of the published misconception work has focussed on primary (elementary) children, few of the misconceptions identified in the literature have been exhibited by the writers of the secondary (high school) textbooks/ syllabuses surveyed. However, where the published misconception work has focussed mainly

on college students and trainee (pre-service) teachers there is a much closer correlation. With a high level of misconception in earth science understanding of trainee teachers, practicing teachers and textbook writers, there is a major task ahead to improve the education of all these groups.

The correlation between the misconceptions of college students/ trainee (preservice) teachers and the textbook/ syllabus survey strengthens the view that the textbook/ syllabus survey provides a useful reflection of the misconceptions of practicing science teachers in the UK. This is because most textbook/ syllabus writers are, or have been, classroom science teachers themselves. Data on the misconceptions of practicing science teachers is difficult to find in the research literature, since there are few opportunities to probe the earth science understanding of classroom science teachers. The insights provided by the textbook/ syllabus survey therefore have increased importance if they provide a better snapshot of the misconceptions involved in normal classroom earth science teaching than other elements of the literature on earth science misconceptions.

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However, one of the disadvantages of textbook/ syllabus surveys is that they do not provide opportunities for analysis of how the misconceptions of the writers developed. They may have come from the teaching the writers themselves received, from erroneous textbook sources, or from overzealous attempts at oversimplification for their pupil readers. Study of how textbook-writers developed their misconceptions would provide a valuable, if problematical, line of future research.

One way of improving education is to ensure that curriculum materials are of high quality and are error-free. This analysis has shown that this is not been the case in the past with many of the materials written for the earth science component of the secondary (high school) science curriculum in England and Wales. Meanwhile, similar situations seem to pertain in US and Spanish teaching materials. The detailed review of the misconceptions in the published materials provided by the reports (King et al, 1998, 2002) and the analysis and review of the data provided by this paper can provide a foundation for future improvement in all these cases. Nevertheless, continued scrutiny will be necessary, so the anecdotal evidence that this scrutiny can be effective, is reassuring.

Table 2 provides the background that will allow future science textbook writers to correct and improve their writing of earth science materials and so offer the opportunity for these improved materials to address the earth science misconceptions of teachers and pupils alike. So, rather than promulgating earth science misconceptions, as in many cases in the past, textbook writers now have the opportunity to improve teaching and learning in this area of key importance to the science curriculum and to the knowledge and understanding of citizens of the future.

83<u>63</u> words.

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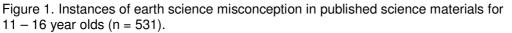
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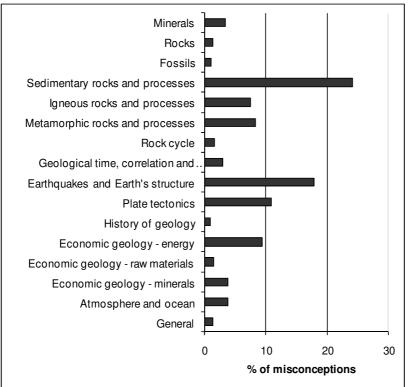
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Table 1. Baseline data obtained from the survey of the earth science content of secondary science textbooks. Spring 2002

| Criterion | Mean findings of | Mean findings of | Mean findings from |
|------------------------------------|---------------------|---------------------|--------------------|
| | the 27 textbooks | the 24 textbooks | the 51 textbooks |
| | for 11-14 year olds | for 14-16 year olds | surveyed in total |
| Percentage of the National | 52% | 57% | 55% |
| Curriculum earth science | | | |
| statements inadequately covered | | | |
| Percentage of earth science | 8.7% | 10.0% | 9.4% |
| (number of pages of earth science | | | |
| relative to the number of pages in | | | |
| the textbook) | | | |
| Mean number of 'Errors/ | 1.1 | 0.9 | 1.0 |
| misconceptions' per page | | | |
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| Table 2. Common earth science 'errors/ oversimplifications' in secondary (11 – 16 |
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| year old) science textbooks in England and Wales – in rank order of frequency. |

| Earth | Prevale nce in | Examples of quotes | Scientific consensus | Discussion | Mis- conception | |
|---|--|---|--|---|--|-------------------------|
| 'error/ oversim plificatio n' | 531 'errors/ oversim plificati ons' found | containing 'errors/ oversimplificatio ns' from textbooks, syllabuses and examinations | view | | of similar significanc e in another science area | |
| A. Weatheri ng/ erosion confusion , eg. 'weatheri ng and erosion are the same' or 'weather causes weatherin g' | 37 7.0% | 'Stone is worn away by the air, wind and rain. This is called weathering.' (O1 - B2, 85 – textbook series for 11-14 year olds) 'Rocks can be worn away in 3 ways: physical weathering, chemical weathering, and, biological weathering.' (N4 - C, 282 – textbook series for 14 – 16 year olds) | 'Weathering. The breakdown of rocks and minerals at the Earth's surface by the action of physical and chemical processes' (Allaby & Allaby, 1991, p401) 'Erosion is the process that moves material resulting from the breakdown, or weathering of bedrock' (Hancock & Skinner, 2000, p314)* | Weathering happens in place and so no solid material is removed. Weathering causes chemical breakdown or physical disintegration (eg. by freeze thaw action, plant root growth). Erosion is the removal of material from the site. Erosion occurs when one or more erosive agents (such as gravity, wind, moving water, or moving ice) <u>remove</u> weathered material (so wind is an agent of erosion, not weathering). [Note: the chemical attack of rainwater on limestone removes material in solution and so is weathering and not erosion]. | Confusing the dissolving of salt and the 'dissolving' of calcium carbonate in acid. | Deleted: removes |
| B. Indicating that the mantle is liquid eg. 'the mantle is made of magma' (see also the section below of nine misconce ptions that the mantle is 'semi - liquid or | 35 6.6% | 'The earth's crust is split into different sections called 'plates'. These plates float around on the hot liquid magma beneath.' C3 - B2, 136 – textbook series for 11-14 year olds) 'Material which enters the liquid mantle can emerge through volcanoes to form igneous rocks. ' (B5 – 96 - a revision guide for 11 – 14 year olds) | 'The asthenosphere (derived from the Greek for 'weak sphere') is the relatively weak, ductile layer in the upper mantle immediately underlying the lithosphere. Although solid at normal strain rates, like the rest of the non- lithospheric mantle, it can deform slowly | The mantle is almost entirely solid, as shown by the fact that it transmits seismic S- waves which can only pass through solid material. There is a zone in the upper mantle between the solid lithosphere above and the solid mantle below, called the asthenosphere that is between 1 and 5% liquid (i.e. is 95 – 99% solid). As the molten material is found as films around the edges of crystals, it allows the solid material of the asthenosphere to | Considering that glass is a liquid when it has the characteristi cs of a solid | |

International Journal of Science Education

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| ʻsemi- solid') | | | in solid state creep.' (Hancock & Skinner, 2000, p47) 'This view, that the crust is a relatively thin layer of solid rock on a liquid interior, became widely prevalent until about a century ago, when it was shown to be unsound.' (Duff, 1993, p12) | flow very slowly. However, the mantle beneath can also flow, even though it is completely solid. A good analogy is ice that, although solid (and capable of being broken by a hammer) can flow downhill in glaciers. When it is near its melting point it can flow more easily. | |
|---|------------|--|--|---|---|
| C. Plates incorrectl y described as made of crust, eg. 'plates are made of crust' or 'crustal plates' | 25 4.7% | 'Plates can be made from oceanic or continental crust' (L8 - 106 - a) chemistry textbook for 14 - 16 year olds) ' the Earth's crust consists of a number of pieces called plates' (L3 - 34 - a) examination syllabus for 14 - 16 year olds) | p12) 'Plate. A segment of the lithosphere which is bounded by plate margins' (Allaby & Allaby & Allaby, 1991, p284) 'Lithosphere. The upper (oceanic and continental) layer of the solid Earth, comprising all crustal rocks and the brittle part of the uppermost mantle.' (Allaby & Allaby, 1991, p219) | The tectonic plates are plates of rigid lithosphere around 100 km thick. They overlie the ductile asthenosphere beneath, which flows slowly, moving the plates - thus there is a physical boundary between the solid lithosphere and the ductile asthenosphere (the 1300°C isotherm). The lithosphere comprises the crust and the uppermost mantle, which are chemically different but both physically solid and rigid. The crust is around 7 km thick in oceanic areas and averages 35 km thick in continental areas – much thinner than the lithosphere. | Thinking that leaves are made of a layer of palisade cells only. |
| D. Indicating that sediment ary rocks are formed by compress ion only, eg. 'sediment ary rocks are | 23 4.3% | 'Layers of sediment form sedimentary rock when put under great pressure.' (L14 – B2, 95 – textbook series for 11 -14 year olds) 'The rocks made when sediments settle under pressure are called | 'Lithification. The process of changing unconsolidate d sediment into rock. This involves cementation of the grains, but not necessarily compaction.' (Allaby & Allaby, 1991, | Most sedimentary rocks cannot be formed by compaction alone; some 'cementation' is required to 'glue' the grains together. Fluids flowing through the pore spaces deposit natural mineral 'cement'. Only fine- grained sediment such as mud can be changed into sedimentary rocks like mudstone or shale by the compression of | Considering that plants need only a source of light to photo- synthesise. |

| formed when sediment s are compress ed by the mass of the overlying materials' | | sedimentary rocks.' (C5 - B1, 111 – textbook series for 14 – 16 year olds) | p218) | the overlying rocks alone, sandstones and limestones need cementation. | |
|--|------------|--|--|--|--|
| E. Oil described as forming from animals, eg. 'oil and gas formed from dead sea creatures' (often implying the remains of fish and other large animals) | 14 2.6% | 'Crude oil is made from the decomposition of the bodies of the same sea creatures whose shells and skeletons make up limestone.' (O1 - B2, 90 - textbook series for 11 – 14 year olds) 'When these creatures died partial decomposition of the remains produced crude oil and the natural gas associated with it.' (L15, 140 – revision guide for 16 year olds) | 'Oil and gas are derived almost entirely from decayed plants and bacteria.' (Clark et al. 1997, p2). 'Source rocks for oil and gas are usually fine-grained sediments rich in organic matter derived from bacterial and chemical alteration of algae, bacteria or land plants. Organic sediments, such as coals, can also act as source rocks, principally for natural gas' (Hancock & Skinner, 2000, p810) | Oil and some natural gas are formed as microscopic plankton become buried and heated in the Earth's crust. The oil-producing plankton is mostly microscopic plants. Most natural gas is formed as buried land vegetation becomes coal | Thinking that plastics are made from coal |
| F. Incorrect definition s of sediment ary terms, eg. 'sediment is just particles | 11 2.1% | 'sediment = Particles that settle out from a suspension.' (C2 – BII, 151 – textbook series for 11 – 14 year olds) 'Understand that weathering of rocks can | 'Sediments are accumulations that were deposited in layers from a fluid (water or air) at the Earth's surface.' (Hancock & Skinner, 2000, 2044) | Sediments are not only deposited in water, but can be deposited by gravity, wind or melting ice. They are transported in fluids (water or air) by rolling, sliding, bouncing or in suspension and are deposited when the energy of the | Considering that plants = trees and flowers |
| that settle out of water' and 'there are just two sorts of physical weatherin | | produce particles of rock which can settle out from rivers as sediments e.g. limestone, mudstone, rock salt.' (L3 – 33 – science | p944) 'Weathering. The group of processes, such as the chemical action of rainwater and of plants and | transporting medium falls. Weathering involves a range of processes that usually act together. Several different physical, biological and chemical weathering processes are involved. | 2 |

| g' or 'there are just two sorts of chemical weatherin g' | | examination syllabus for 16 year olds) | bacteria and the mechanical action of changes of temperature, whereby rocks on exposure to the weather change in character, decay and finally crumble into soil' (AGI, 1962, p536) | | |
|--|------------|---|--|---|--|
| G. Indicating that metamor phism is caused by overburd en pressure, eg. 'metamor phism is caused when rocks are buried and heated' or 'metamor phic rocks are formed by the pressure of the overlying rocks and heat' | 10 1.9% | 'Metamorphic: Some igneous and sedimentary rocks may be buried. Heat and pressure change these rocks. This change makes metamorphic rocks.' (N3 - B9, 38 – textbook series for 11 – 14 year olds) 'Metamorphic rocks as those formed from rocks which became buried deep underground' S1/2 – 50 – science examination syllabus for 16 year olds) | 'Regional metamorphism . The recrystallisatio n of pre- existing rocks in response to simultaneous changes of temperature, lithostatic pressure and, in many cases, shear stress, occurring in orogenic belts where lithospheric plates are converging' (Allaby & Allaby, 1991, p311) 'Contact metamorphism . The recrystallisatio n of rocks surrounding an igneous intrusion in response to the heat supplied by the intrusion.' (Allaby & Allaby, 1991, p83) | Widespread (regional) metamorphism that produces slates, schists and gneisses requires regimes of very high compression and heating These conditions only occur when plates collide. There is normally not enough compression or heating produced by burial alone to cause metamorphism. Meanwhile, baking by hot igneous intrusions can cause localised metamorphism. | Thinking that water can boil at 50 °C at normal (atmospheri c) pressures |
| H. The thickness es of Earth layers are given or shown | 10 1.9% | 'The rock surface of the Earth is at most 10 kilometres thick.' (H2 - BB, 130 – textbook series for 11 – 14 year | 'The thickness of the lithosphere varies between about 80 – 125 km, compared with | The crust comprises the continental crust and the oceanic crust, with a mean thickness of around 18 km. The crust is chemically different from the mantle so the | Thinking that skin is 0.1 mm thick (skin actually averages 1 -2 mm |

| incorrectl y | | olds) 'Crust At its thickest it is about 40km.' (H4 – 166 – textbook for 14 – 16 year olds) Earth cross- section diagram showing the core too small and the crust far too thick. C1 - C 147 – textbook for 14 – 16 year olds) | an average crustal thickness of 35 km for the continents and 7 km for the oceans' (Duff, 1993, p599) 'Continental crust averaging 35km and reaching 70 km in some places.' (Duff, 1993, p14) 'The boundary [of the core] with the mantle lies at a depth of c2900 km from the surface and the core therefore occupies over 50 percent of the radius.' (Duff, 1993, p13) | boundary, the Moho, is a chemical boundary. This boundary does not influence plate tectonics. The tectonic plates are of lithosphere, comprising the crust and the outermost mantle and are around 100 km thick. The lithosphere is solid and rigid and the boundary between it and the asthenosphere beneath is the 1300°C isotherm. The asthenosphere is the 'weak sphere' of the Earth and, although 95 – 99% solid, is able to flow, affecting plate movement. The base of the asthenosphere is about 350km down. The mantle continues down to the core/mantle boundary at 2891 km depth, a boundary between the solid mantle and the liquid outer iron-rich core that is both mechanical and chemical. The mechanical boundary between the liquid outer core and solid inner core is at 5149 km depth. The centre of the Earth | thick) |
|---|------------|--|---|---|---|
| I. Misunder standing of 'ore', eg. 'rocks containin g metals are called ores' | 10 1.9% | 'Rocks containing metals or metal compounds are called ores.' (C3 - B2, 124 – textbook series for 11 – 14 year olds) 'Ores are mixtures of rocks and minerals.' (C5 - B1, 104 – textbook series for 14 – 16 year | 'Ore. A mineral or rock that can be worked economically' (Allaby & Allaby, 1991, p261) | is 6371 km deep. The minerals that make up most rocks contain metal compounds, but are not ores. The term 'ore' has an economic context. A rock or mineral deposit is only an ore if it is rich enough for potential commercial exploitation. | Considering that a coal seam 1 mm thick is a useful energy resource |
| J. Misunder standing of freeze/th aw process, | 9 1.7% | olds) 'In cold weather the water freezes and expands. The forces generated by the ice cause pieces of rock to snap off.' (J1 – | 'Water expends on freezing, and through repeated alternations of frost and thaw | Freezing alone does not cause physical weathering of rocks; many cycles of freezing and thawing are necessary. During each thaw, water penetrates | Thinking that a plant will die if you forget to water it for one day. |

Page 125 of 130

International Journal of Science Education

| are broken by freezing' | series for 11 – 14 year olds) 'Rocks are weathered by the freezing of water ' (B5 – 96 – revision guide for 14 year olds) | pores and cracks, the rocks are relentlessly broken to bits' (Duff, 1993, p22) | crack widened by the previous freeze, until a fragment eventually breaks off. The expansion of water on freezing, causing this process, can be demonstrated by freezing a sealed syringe of 10 ml of water, (Williams, 1984). | |
|---|--|--|--|---|
| K. 9 Misunder 1.7 standings of limestone and chalk, eg. 'limeston e only has grey porous forms' or 'chalk is made of the skeletons of sea creatures' | | 'Limestones exhibit the same variety of grain sizes, textures and sedimentary structures as siliclastic deposits [conglomerate s, sandstones, mudstones, etc.] and, in addition, others not exhibited by siliclastic deposits.' (Hancock & Skinner, 2000, p605) 'The Cretaceous chalks are composed largely of coccoliths (Tucker, 1982, p155) 'Coccolithopho rids are planktonic algae which have a skeleton composed of numerous calcareous plates called coccoliths. (Tucker 1982, p111) | Limestones occur in a wide variety of textures and colours. Some are soft and porous, others are harder and at hand specimen scale are non- porous (but can be porous at a larger scale because of cracks and fissures). Chalk is a type of limestone formed mainly of the microscopic plates of planktonic single celled plants (ie they are microscopic plant remains) | Thinking that Iron and steel are different metals – and steel is mainly carbon |

| Mineral/r1.5%dense rockbe defined as a naturallyor compound. Thus a mineral has a definitemixtures andockOlivine is an example of aa naturallymineral has a definiteandconfusionexample of a silicate rockoccurring homogenouschemical composition, atomic structure and physical properties (that iron filingsand 'rock'example of an example of ansolid, inorganicallyphysical properties (that iron filings | | International Journal of Science Education | | | | |
|--|---|--|--|---|--|--|
| M. 8 Olivine is a hard A mineral is an element or compound. Thus a mineral has a definite or the composition or mineral is an or compound. Thus a mineral has a definite or the composition or mineral is an element or composition, and an anturally or arrongen or the composition and an and and | Indicating that the mantle is semi- liquid or | | See 'the mantle is I | iquid' section abo | ve | |
| | solid M. Mineral/r ock confusion , eg. ''mineral' and 'rock' mean the | | dense rock Olivine is an example of a silicate rock Olivine is an example of an igneous rock Olivine and similar minerals are sometimes found' ($L4 - 11$ - question in a science examination for 16 year olds) 'Some minerals, like limestone, are found in rocks on their own.' $L8 -$ 47 - textbook for | be defined as a naturally occurring homogenous solid, inorganically formed, with a definite chemical composition or a definite range of composition, and an ordered atomic arrangement.' (Hancock & Skinner, 2000, p692) 'Rock. A consolidated or unconsolidate d aggregate of minerals or organic matter. The minerals may be all of one type or of many types ' (Allaby & Allaby, 1991, p319) | or compound. Thus a mineral has a definite chemical composition, atomic structure and physical properties (that vary between fixed limits). A rock is a mixture of one or more minerals (or fragments of rocks or fossils) so the compositions and structures of most rocks can be very variable. However, some rocks are formed of predominantly one mineral, such as limestone (largely calcite), quartzite (largely quartz) and rock salt (largely halite). Igneous rocks usually contain more than one | and compounds (eg. a mixture of iron filings and sulphur with iron |

| N. Bas and granite can for from th same magma eg. 'a single magma can produc granite basalt' 'granite comes from volcan s' | 1.5% m le a, a or or e | 'Molten rock which emerges through volcanoes is called lava. As this cools it forms a variety of solids and these are known as igneous rock – one example is granite.' (L11 – 100 – textbook for 11 – 14 year olds) Edinburgh Castle stands on a 'plug' of granite that was once inside a volcano. N4 - C, 282 – textbook series for 14 – 16 year olds) | 'Basalt, a dark- coloured, fine- grained extrusive igneous rock containing not more than 53 wt% SiO ₂ ' (Allaby & Allaby, 1991, 34) 'Granite. A light-coloured, coarse grained igneous rock ' (Allaby & Allaby, 1991, p164) 'Granites are intrusive igneous rocks that contain large amounts of silica (SiO ₂)' (Hancock & Skinner, 2000, p464) | Granite and basalt are chemically very different and so cannot change from one to the other. When the mantle partially melts, dark magma forms. This iron- rich, silica-poor magma produces basalt if it cools quickly at the surface or coarse- grained gabbro if it cools slowly at depth. When the crust partially melts, a paler, silica-rich magma is formed. This is rarely erupted as lava, but can explode as ash or pumice. Usually this magma crystallises slowly underground to form coarse-grained granite. | Confusing caustic soda (sodium hydroxide) with common salt (sodium chloride) |
|--|---|--|--|---|---|
| O. Oil indicat as forming millions of year ago, eg 'oil formec once ir geolog I time' | g s g i n ica | 'Coal, oil and natural gas are called fossil fuels. They were made from plants and animals that lived on Earth about 100 million years ago.' (N3 B7, 42 – textbook series for 11 – 14 year olds) 'Oil was formed from the remains of organisms which lived millions of years ago.' (N1/2 – 38 – science examination syllabus for 16 year olds) | 'In the North Sea oil forms at 3 – 4.5 km depth, gas at 4 – 6 km Burial to these depths occurs in areas where the Earth's crust is sagging These processes continue today ' (Clark et al. 1997, p3) | Most of the gas in the UK was formed from coals deposited as swamp deposits some 300 million years ago. Most of the oil and some gas were formed from algae and bacteria that settled on the sea floor around 140 million years ago. These formed source rocks that were heated and compressed to release their oil and gas and are still slowly releasing them today. | Thinking that evolution happened millions of years ago |

Key: N4 - C, 282. Reference to textbook, syllabus or examination source of quote containing 'error/ oversimplification'.

* In the past, the term 'erosion' has been used more broadly to include weathering, but this is not the normal usage in scientific discussion today.

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Table 2 Key references relating to earth science missencentions

| Category | Key texts | | | |
|---|---|--------------------------------------|--|--|
| Minerals, rocks and | Piaget, 1929; Ault, 1984; Happs, 1982, 1985a, 1985b; Hawley, 2002; Dove, | | | |
| fossils | 1996, 1998; Oversby, 1996; Ford, 2003, 2005 | | | |
| Sedimentary rocks and processes | Cosgrove & Osborne, 1983; Dove, 1997 | Happs, 1982; Driver et al, 1994b; | | |
| Igneous rocks and processes | Lillo, 1994; Dove, 1998; Libarkin et al, 2005; Dahl et al, 2005 | Stofflett, 1994; Kusnick, 2002; | | |
| Metamorphic rocks and processes | None specific to this topic | Blake, 2004; | | |
| The rock cycle | Stofflett, 1993; Ford 2003; Kali et al, 2003; Sibley et al, 2007 | | | |
| Geological time, | Ault,1982; Trend, 1998, 2000, 2001; Dodick & Orion, 2003; Hidalgo & Otero, | | | |
| correlation and dating | 2004; Libarkin et al, 2005; Libarkin & Anderson, 2005; Dahl et al, 2005 | | | |
| Earthquakes and the structure of the Earth | Leather, 1987; Schoon, 1992, 1995; Ross & Shuell, 1993; Lillo, 1994; Sharp et al, 1995; Marques & Thompson, 1997a; King, 2000; Tsai, 2001; Libarkin et al, 2005; Steer et al, 2005; Rutin & Sofer, 2007 | | | |
| Plate tectonics Margues & Thompson, 1997b; King, 2000; Libarkin et al, 2005; Libarkin, 2006 | | | | |
| History of geology | None specific to this topic | | | |
| Economic geology | Leather, 1987 | | | |

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Table 4. Comparison between earth science misconceptions common in the literature and those most frequently found in the textbook/ svilabus surveys

| Category | Misconceptions of children, students and teachers commonly cited in existing literature | Misconceptions identified in the textbook/syllabus surveys in order of frequency |
|---|--|---|
| Minerals, rocks and fossils | The terms 'rock' and 'mineral' often used in a non-scientific sense and/or misunderstood | Mineral/rock confusion Mineral definition Rock definition Rock hardness |
| Sedimentary rocks and processes | Confusion between 'weathering' and 'erosion' Little understanding that sedimentary rocks were formed by sedimentary processes | Weathering/erosion confusion Formation of sedimentary rocks by compression only Sedimentary definitions Freeze-thaw mechanism Chalk/limestone confusion |
| Igneous rocks and processes | Erroneous ideas about volcanoes, including that their magma originates in the core and that they only occur in warm climates or on islands | Granite forms in volcanoes Igneous definitions Magma comes only from the mantle |
| Metamorphic rocks and processes | Metamorphic processes wrongly associated with metamorphosis in animals | Metamorphic rocks formed by overburden pressure and heat Metamorphic rocks never contain fossils |
| The rock cycle | The rock cycle not understood as an explanatory model | The rock cycle is continuous |
| Geological time, correlation and dating | Most people had poor chronological understanding of geological events | Rocks dated by radioactivity of 'rocks' or fossils |
| Earthquakes and the structure of the Earth | Little understanding of the locations of earthquakes Little understanding of the causes of earthquakes Poor knowledge of the structure of the Earth and of the state (solid, liquid, etc.) of its layers | Mantle is liquid/magma Thickness of Earth layers incorrect Mantle is semi-liquid/semi-solid |
| Plate tectonics | Poor understanding of the nature of continents and oceans Little understanding of the concept of 'tectonic plate' Poor knowledge of the links between earthquakes, volcanoes and plate movement | Plates made of crust Many single instances of misconception |
| History of geology | None found | Wegener proposed plate tectonics |
| Economic geology | Thinking that oil formed from dead sea creatures Indicating that oil is trapped in [largish] holes under the ground | Oil formed from animals Oil formed millions of years ago Misunderstanding of 'ore' How traps are formed Geothermal energy is renewable |
| Atmosphere and ocean | Thinking that the hole in the ozone layer results in global warming Little understanding of the link between fossil fuels and the carbon cycle Poor understanding of the role of | Gases are acidic Incomplete carbon cycle |

CO₂ in global warming