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

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Journal:	*International Journal of Science Education*
Manuscript ID:	TSED-2008-0166.R2
Manuscript Type:	Research Paper
Keywords:	earth science education, high school, misconception, secondary school, alternative conception
Keywords (user):	textbooks

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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.

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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.

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Key Words:
earth science education; high school; misconception; secondary school; textbooks.

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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 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

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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 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.

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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.

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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.

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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.

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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.

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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.

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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.

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

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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' … ; 'misunderstandings' … ; 'errorneous ideas' …; and 'mistakes' ...' (p178).

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

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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.

A comparison of the textbook/ syllabus 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 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.

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Deleted: Given that pupils and pre-service teachers carry these misconceptions about minerals, rocks and fossils, it is not surprising that similar misconceptions are found amongst the writers of science teaching materials.

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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 rock-forming processes] presented.’ (p495). Kusnick (2002), in another survey of pre-service 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

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 find it very difficult to conceptualise long periods of time. Libarkin et al (2005) found that US college students held a number of misconceptions about the dating of the formation of the Earth and the formation of life. In further work Libarkin & Anderson (2005) found that students had poor ideas of the scale of geological time, the occurrence of events in geological history and absolute age dating. Meanwhile, Dahl et al (2005) working with US practising teachers, found that they were fairly comfortable with relative dating, but not comfortable with allocating dates to 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 geological time until they reached the age of 12 or older.

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

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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 volcanoes …' 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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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

Marques 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.

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.

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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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 pre-service 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 …' (p76).

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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 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).

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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 on 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.

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The correlation between the misconceptions of college students/ trainee (pre-service) 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.

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.

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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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ACKNOWLEDGEMENTS

I am most grateful to the reviewers of an earlier draft of this paper, who have enabled me to greatly improve the original.

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Figure 1. Instances of earth science misconception in published science materials for 11 – 16 year olds (n = 531).

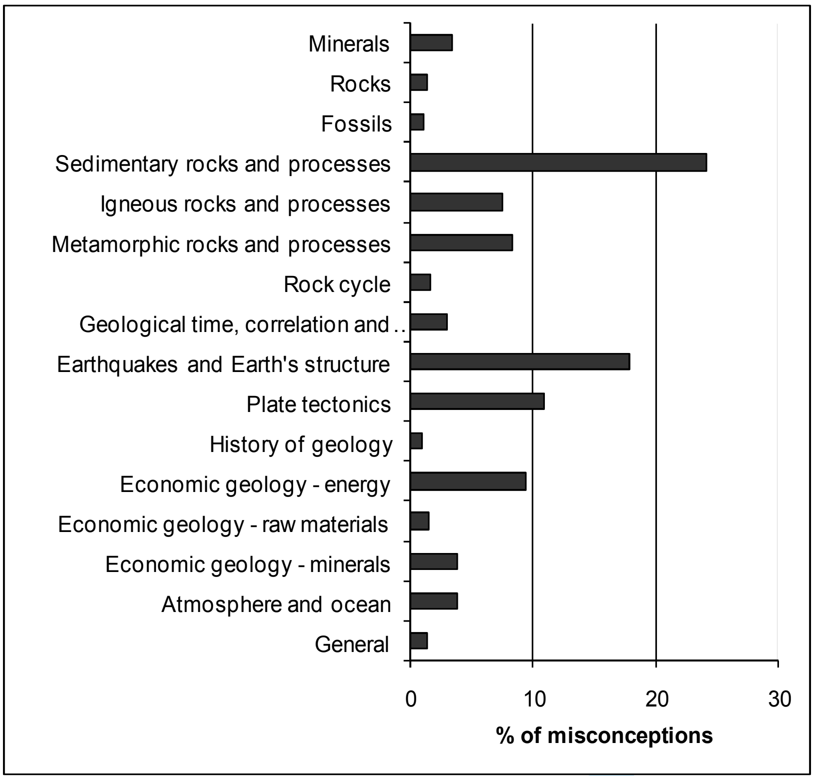

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Table 1. Baseline data obtained from the survey of the earth science content of secondary science textbooks, Spring 2002.

Criterion	Mean findings of 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
Percentage of the National Curriculum earth science statements inadequately covered	52%	57%	55%
Percentage of earth science (number of pages of earth science relative to the number of pages in the textbook)	8.7%	10.0%	9.4%
Mean number of 'Errors/ misconceptions' per page	1.1	0.9	1.0

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

Earth science 'error/ oversimplification'	**Prevalence in 531 'errors/ oversimplifications' found**	**Examples of quotes containing 'errors/ oversimplifications' from textbooks, syllabuses and examinations**	**Scientific consensus view**	**Discussion**	**Mis-conception of similar significance in another science area**
A. Weathering/ erosion confusion, eg. 'weathering and erosion are the same' or 'weather causes weathering'	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) removes 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.
B. Indicating that the mantle is liquid eg. 'the mantle is made of magma' (see also the section below of nine misconceptions 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 characteristics of a solid

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'semi-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 incorrectly 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 – an examination syllabus for 14 – 16 year olds)	'Plate. A segment of the lithosphere which is bounded by … plate margins' (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 sedimentary rocks are formed by compression only, eg. 'sedimentary 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 unconsolidated 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.

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formed when sediments are compressed 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 definitions of sedimentary terms, eg. 'sediment is just particles that settle out of water' and 'there are just two sorts of physical weatherin	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 produce particles of rock which can settle out from rivers as sediments … e.g. limestone, mudstone, rock salt.' (L3 – 33 – science	'Sediments are accumulations … that were deposited in layers from a fluid (water or air) … at the Earth's surface. ' (Hancock & Skinner, 2000, p944) 'Weathering. The group of processes, such as the chemical action of rainwater and of plants and	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 transporting medium falls. Weathering involves a range of processes that usually act together. Several different physical, biological and chemical weathering processes are involved.	Considering that plants = trees and flowers

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g' or 'there are just two sorts of chemical weathering'		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 metamorphism is caused by overburden pressure, eg. 'metamorphism is caused when rocks are buried and heated' or 'metamorphic 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 recrystallisation 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 recrystallisation 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 (atmospheric) pressures
H. The thicknesses 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

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incorrectly		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 is 6371 km deep.	thick)
I. Misunderstanding of 'ore', eg. 'rocks containing 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 olds)	'Ore. A mineral or rock that can be worked economically' (Allaby & Allaby, 1991, p261)	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. Misunderstanding of freeze/thaw process,	9 1.7%	'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.

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eg. 'rocks are broken by freezing'		C100 – textbook series for 11 – 14 year olds) 'Rocks are weathered by the freezing of water …' (B5 – 96 – revision guide for 14 year olds)	in water-filled pores and cracks, the rocks are relentlessly broken to bits' (Duff, 1993, p22)	more deeply into the 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. Misunderstandings of limestone and chalk, eg. 'limestone only has grey porous forms' or 'chalk is made of the skeletons of sea creatures'	9 1.7%	'Limestone is a grey rock with a rough powdery texture. J1 – C99 - textbook series for 11 – 14 year olds) 'Chalk: A soft crumbly rock composed of the calcium carbonate shells of prehistoric sea animals. H2 - BB, 93 – textbook series for 11 – 14 year olds) 'Chalk is one form of calcium carbonate …. Limestone is the most important form of calcium carbonate… The third form of calcium carbonate is marble.' N4 - C, 121 – textbook series for 14 -16 year olds)	'Limestones … exhibit the same variety of grain sizes, textures and sedimentary structures as siliclastic deposits [conglomerates, 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) 'Coccolithophorids … 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

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L. Indicating that the mantle is semi-liquid or semi-solid	9 1.7%	See 'the mantle is liquid' section above			
M. Mineral/rock confusion, eg. ''mineral' and 'rock' mean the same'	8 1.5%	'Olivine is a hard, 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 14 – 16 year olds)	'A mineral can 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 unconsolidated aggregate of minerals or organic matter. The minerals may be all of one type … or of many types …' (Allaby & Allaby, 1991, p319)	A mineral is an element 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 mineral.	Confusing mixtures and compounds (eg. a mixture of iron filings and sulphur with iron sulphide)

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N. Basalt and granite can form from the same magma, eg. 'a single magma can produce granite or basalt' or 'granite comes from volcanoes'	8 1.5%	'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 indicated as forming millions of years ago, eg. 'oil formed once in geological time'	7 1.3%	'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.

Table 3. Key references relating to earth science misconceptions.

Category	Key texts	
Minerals, rocks and fossils	Piaget, 1929; Ault, 1984; Happs, 1982, 1985a, 1985b; Hawley, 2002; Dove, 1996, 1998; Oversby, 1996; Ford, 2003, 2005	
Sedimentary rocks and processes	Cosgrove & Osborne, 1983; Dove, 1997	Happs, 1982; Driver et al, 1994b; Stofflett, 1994; Kusnick, 2002; Blake, 2004;
Igneous rocks and processes	Lillo, 1994; Dove, 1998; Libarkin et al, 2005; Dahl et al, 2005	
Metamorphic rocks and processes	None specific to this topic	
The rock cycle	Stofflett, 1993; Ford 2003; Kali et al, 2003; Sibley et al, 2007	
Geological time, correlation and dating	Ault,1982; Trend, 1998, 2000, 2001; Dodick & Orion, 2003; Hidalgo & Otero, 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	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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Table 4. Comparison between earth science misconceptions common in the literature and those most frequently found in the textbook/ syllabus 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

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	CO_2 in global warming	

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Meadows & Wiesenmayer (1999) identified a common misconception among schoolchildren as, ‘the “hole” in the ozone layer allows a greater penetration of sunlight which results in raising the temperature of the earth [global warming].’ (p236). This misconception is also held by many pre-service primary (elementary) teachers, as noted in a review of the literature by Summers et al (2000), and in the UK practising primary (elementary) teachers they surveyed. Meanwhile, Khalid (2003) reports a high frequency of this misconception among US pre-service secondary (high) school teachers as well.

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Summers et al (2000) also probed understanding of the carbon cycle in practising UK primary (elementary) teachers, finding that the ‘locking up’ of carbon in fossil fuels was understood by less than half the teachers and that most did not grasp the idea that large quantities of ‘ancient carbon’ are being released into the atmosphere by the burning of fossil fuels. Their work on researching understanding of the greenhouse effect showed that few of the teachers were aware of how the atmosphere causes the greenhouse effect or how human activities can enhance this. In Summers et al (2001), they report, ‘striking features …were … practising primary teachers’ low awareness of, or uncertainty about, … the role of carbon dioxide in global warming …’ (p50/1)

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Khalid’s (2003) work, using the methodology of Dove (1996b), showed that the US pre-service secondary (high) school teachers surveyed held a range of misconceptions about the environment, concerning in particular, the greenhouse effect, ozone and acid rain. He also reported the work of Hooper (1988) and Subbarani (1991) indicating that practising science teachers hold similar misconceptions.

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Thus it is surprising that the number of misconception instances relating to the atmosphere and ocean in the textbook/ syllabus surveys was rather smaller than in some other areas of earth science.

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Atmosphere and ocean	Boyes et al, 1993; Dove, 1996b; Groves & Pugh, 1999; Meadows & Wiesenmayer, 1999; Summers et al, 2000, 2001; Khalid, 2003

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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

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

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
Percentage of the National Curriculum earth science statements inadequately covered	52%	57%	55%
Percentage of earth science (number of pages of earth science relative to the number of pages in the textbook)	8.7%	10.0%	9.4%
Mean number of 'Errors/ misconceptions' per page	1.1	0.9	1.0

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

Earth science 'error/ oversimplification'	Prevalence in 531 'errors/ oversimplifications' found	Examples of quotes containing 'errors/ oversimplifications' from textbooks, syllabuses and examinations	Scientific consensus view	Discussion	Mis-conception of similar significance in another science area
A. Weathering/ erosion confusion, eg. 'weathering and erosion are the same' or 'weather causes weathering'	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) removes 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.
B. Indicating that the mantle is liquid eg. 'the mantle is made of magma' (see also the section below of nine misconceptions 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 characteristics of a solid

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'semi-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 incorrectly 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 – an examination syllabus for 14 – 16 year olds)	'Plate. A segment of the lithosphere which is bounded by … plate margins' (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^{o}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 sedimentary rocks are formed by compression only, eg. 'sedimentary 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 unconsolidated 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.

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formed when sediments are compressed 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 definitions of sedimentary terms, eg. 'sediment is just particles that settle out of water', and 'there are just two sorts of physical weatherin	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 produce particles of rock which can settle out from rivers as sediments … e.g. limestone, mudstone, rock salt.' (L3 – 33 – science	'Sediments are accumulations … that were deposited in layers from a fluid (water or air) … at the Earth's surface. ' (Hancock & Skinner, 2000, p944) 'Weathering. The group of processes, such as the chemical action of rainwater and of plants and	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 transporting medium falls. Weathering involves a range of processes that usually act together. Several different physical, biological and chemical weathering processes are involved.	Considering that plants = trees and flowers

g' or 'there are just two sorts of chemical weathering'		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 metamorphism is caused by overburden pressure, eg. 'metamorphism is caused when rocks are buried and heated' or 'metamorphic 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 recrystallisation 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 recrystallisation 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 (atmospheric) pressures
H. The thicknesses 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

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incorrectly		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 is 6371 km deep.	thick)
I. Misunderstanding of 'ore', eg. 'rocks containing 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 olds)	'Ore. A mineral or rock that can be worked economically' (Allaby & Allaby, 1991, p261)	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. Misunderstanding of freeze/thaw process,	9 1.7%	'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.

eg. 'rocks are broken by freezing'		C100 – textbook series for 11 – 14 year olds) 'Rocks are weathered by the freezing of water …' (B5 – 96 – revision guide for 14 year olds)	in water-filled pores and cracks, the rocks are relentlessly broken to bits' (Duff, 1993, p22)	more deeply into the 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. Misunderstandings of limestone and chalk, eg. 'limestone only has grey porous forms' or 'chalk is made of the skeletons of sea creatures'	9 1.7%	'Limestone is a grey rock with a rough powdery texture. J1 – C99 - textbook series for 11 – 14 year olds) 'Chalk: A soft crumbly rock composed of the calcium carbonate shells of prehistoric sea animals. H2 - BB, 93 – textbook series for 11 – 14 year olds) 'Chalk is one form of calcium carbonate …. Limestone is the most important form of calcium carbonate… The third form of calcium carbonate is marble.' N4 - C, 121 – textbook series for 14 -16 year olds)	'Limestones … exhibit the same variety of grain sizes, textures and sedimentary structures as siliclastic deposits [conglomerates, 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) 'Coccolithophorids … 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

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L. Indicating that the mantle is semi-liquid or semi-solid	9 1.7%	See ‘the mantle is liquid’ section above			
M. Mineral/rock confusion, eg. ‘’mineral’ and ‘rock’ mean the same’	8 1.5%	‘Olivine is a hard, 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 14 – 16 year olds)	‘A mineral can 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 unconsolidated aggregate of minerals or organic matter. The minerals may be all of one type … or of many types …’ (Allaby & Allaby, 1991, p319)	A mineral is an element 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 mineral.	Confusing mixtures and compounds (eg. a mixture of iron filings and sulphur with iron sulphide)

N. Basalt and granite can form from the same magma, eg. 'a single magma can produce granite or basalt' or 'granite comes from volcanoes'	8 1.5%	'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 indicated as forming millions of years ago, eg. 'oil formed once in geological time'	7 1.3%	'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.

Table 3. Key references relating to earth science misconceptions.

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

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

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Economic geology	Leather, 1987
Atmosphere and ocean	Boyes et al, 1993; Dove, 1996b; Groves & Pugh, 1999; Meadows & Wiesenmayer, 1999; Summers et al, 2000, 2001; Khalid, 2003

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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 model, which 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 currently studied in secondary (high) schools in England and Wales.

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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 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)

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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.

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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.

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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 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).

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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

> 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' … ; 'misunderstandings' … ; 'errorneous ideas' …; and 'mistakes' ...' (p178).

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.

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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).

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.

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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 rock-forming processes] presented.' (p495). Kusnick (2002), in another survey of pre-service 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 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 find it very difficult to conceptualise long periods of time. Libarkin et al (2005) found that US college students held a number of misconceptions about the dating of the formation of the Earth and the formation of life. In further work Libarkin & Anderson (2005) found that students had poor ideas of the scale of geological time, the occurrence of events in geological history and absolute age dating. Meanwhile, Dahl et al (2005) working with US practising teachers, found that they were fairly comfortable with relative dating, but not comfortable with allocating dates to 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 geological time until they reached the age of 12 or older.

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 volcanoes …' 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 earthquakes of different depths are likely to be found.

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

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Plate tectonics

Marques 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).

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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.

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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.

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<u>Even after the limited coverage of the atmosphere and ocean noted above is taken into account, the</u> 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.

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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 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.

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The correlation between the misconceptions of college students/ trainee (pre-service) 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.

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.

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ACKNOWLEDGEMENTS
I am most grateful to the reviewers of an earlier draft of this paper, who have enabled me to greatly improve the original.

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Figure 1. Instances of earth science misconception in published science materials for 11 – 16 year olds (n = 531).

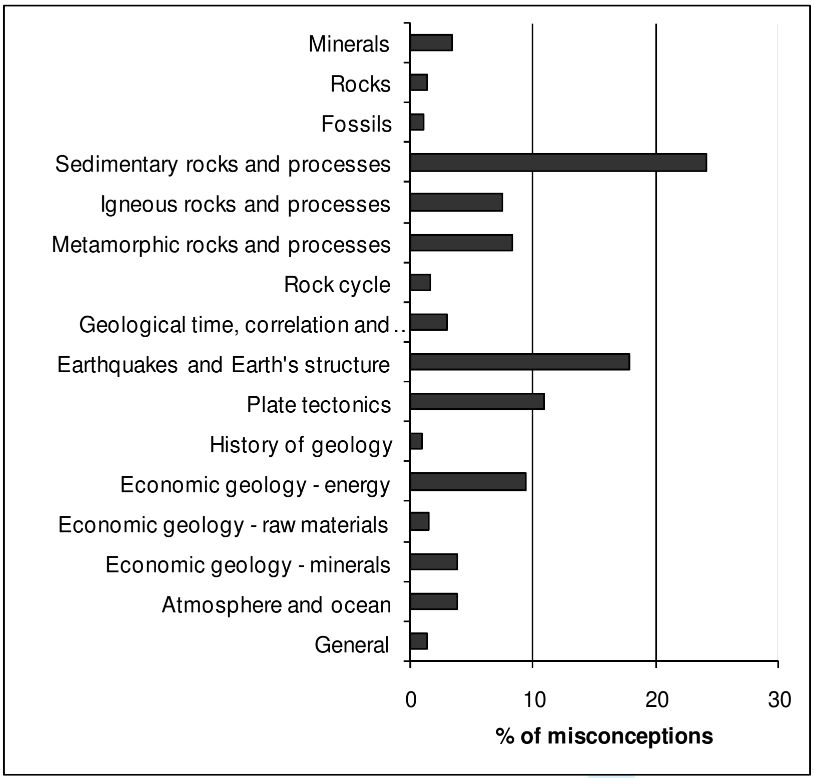

Table 1. Baseline data obtained from the survey of the earth science content of secondary science textbooks, Spring 2002.

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
Percentage of the National Curriculum earth science statements inadequately covered	52%	57%	55%
Percentage of earth science (number of pages of earth science relative to the number of pages in the textbook)	8.7%	10.0%	9.4%
Mean number of 'Errors/ misconceptions' per page	1.1	0.9	1.0

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

Earth science 'error/ oversimplification'	Prevalence in 531 'errors/ oversimplifications' found	Examples of quotes containing 'errors/ oversimplifications' from textbooks, syllabuses and examinations	Scientific consensus view	Discussion	Mis-conception of similar significance in another science area
A. Weathering/ erosion confusion, eg. 'weathering and erosion are the same' or 'weather causes weathering'	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) remove 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.
B. Indicating that the mantle is liquid eg. 'the mantle is made of magma' (see also the section below of nine misconceptions 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 characteristics of a solid

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'semi-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 incorrectly 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 – an examination syllabus for 14 – 16 year olds)	'Plate. A segment of the lithosphere which is bounded by … plate margins' (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^{o}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 sedimentary rocks are formed by compression only, eg. 'sedimentary 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 unconsolidated 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 sediments are compressed 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 definitions of sedimentary terms, eg. 'sediment is just particles that settle out of water' and 'there are just two sorts of physical weatherin	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 produce particles of rock which can settle out from rivers as sediments … e.g. limestone, mudstone, rock salt.' (L3 – 33 – science	'Sediments are accumulations … that were deposited in layers from a fluid (water or air) … at the Earth's surface. ' (Hancock & Skinner, 2000, p944) 'Weathering. The group of processes, such as the chemical action of rainwater and of plants and	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 transporting medium falls. Weathering involves a range of processes that usually act together. Several different physical, biological and chemical weathering processes are involved.	Considering that plants = trees and flowers

g' or 'there are just two sorts of chemical weathering'		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 metamorphism is caused by overburden pressure, eg. 'metamorphism is caused when rocks are buried and heated' or 'metamorphic 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 recrystallisation 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 recrystallisation 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 ^{o}C at normal (atmospheric) pressures
H. The thicknesses 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

incorrectly		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^{o}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 is 6371 km deep.	thick)
I. Misunderstanding of 'ore', eg. 'rocks containing 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 olds)	'Ore. A mineral or rock that can be worked economically' (Allaby & Allaby, 1991, p261)	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. Misunderstanding of freeze/thaw process,	9 1.7%	'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.

eg. 'rocks are broken by freezing'		C100 – textbook series for 11 – 14 year olds) 'Rocks are weathered by the freezing of water …' (B5 – 96 – revision guide for 14 year olds)	in water-filled pores and cracks, the rocks are relentlessly broken to bits' (Duff, 1993, p22)	more deeply into the 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. Misunder standings of limestone and chalk, eg. 'limeston e only has grey porous forms' or 'chalk is made of the skeletons of sea creatures'	9 1.7%	'Limestone is a grey rock with a rough powdery texture. J1 – C99 - textbook series for 11 – 14 year olds) 'Chalk: A soft crumbly rock composed of the calcium carbonate shells of prehistoric sea animals. H2 - BB, 93 – textbook series for 11 – 14 year olds) 'Chalk is one form of calcium carbonate …. Limestone is the most important form of calcium carbonate… The third form of calcium carbonate is marble.' N4 - C, 121 – textbook series for 14 -16 year olds)	'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

L. Indicating that the mantle is semi-liquid or semi-solid	9 1.7%	See 'the mantle is liquid' section above			
M. Mineral/rock confusion, eg. ''mineral' and 'rock' mean the same'	8 1.5%	'Olivine is a hard, 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 14 – 16 year olds)	'A mineral can 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 unconsolidated aggregate of minerals or organic matter. The minerals may be all of one type … or of many types …' (Allaby & Allaby, 1991, p319)	A mineral is an element 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 mineral.	Confusing mixtures and compounds (eg. a mixture of iron filings and sulphur with iron sulphide)

N. Basalt and granite can form from the same magma, eg. 'a single magma can produce granite or basalt' or 'granite comes from volcanoes'	8 1.5%	'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 indicated as forming millions of years ago, eg. 'oil formed once in geological time'	7 1.3%	'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.

Table 3. Key references relating to earth science misconceptions.

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

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

	CO_2 in global warming	