What on Earth

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Photograph courtesy DigitalGlobe

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Tsunami!

Most of the world's population added this new word to their lexicons at year end 2004. Peter and I had almost finished the "Winter version" of What On Earth, but as discussions of the massive earthquake near Banda Aceh, Sumatra, and the unprecedented tsunami waves that ravaged the shorelines of southeast Asia dominated the news we thought that we should modify this issue. By now almost all people on Earth are aware of the scale of the disaster, although figures on deaths and damage are still being added to the total. So far more than 150,000 are known to be dead, almost 100,000 in Indonesia alone, with an additional 30,000 in Sri Lanka and the damage undoubtedly runs into billions of dollars. The number of dead in this tragedy ranks the Banda Aceh earthquake and associated tsunamis as the seventh largest recorded in human history. Certainly the almost incessant visual coverage provided by the world's media has etched the scale of human suffering and grief on everyone's minds. But what is the geological background to this story, and what were the elements that brought the catastrophe to reality?

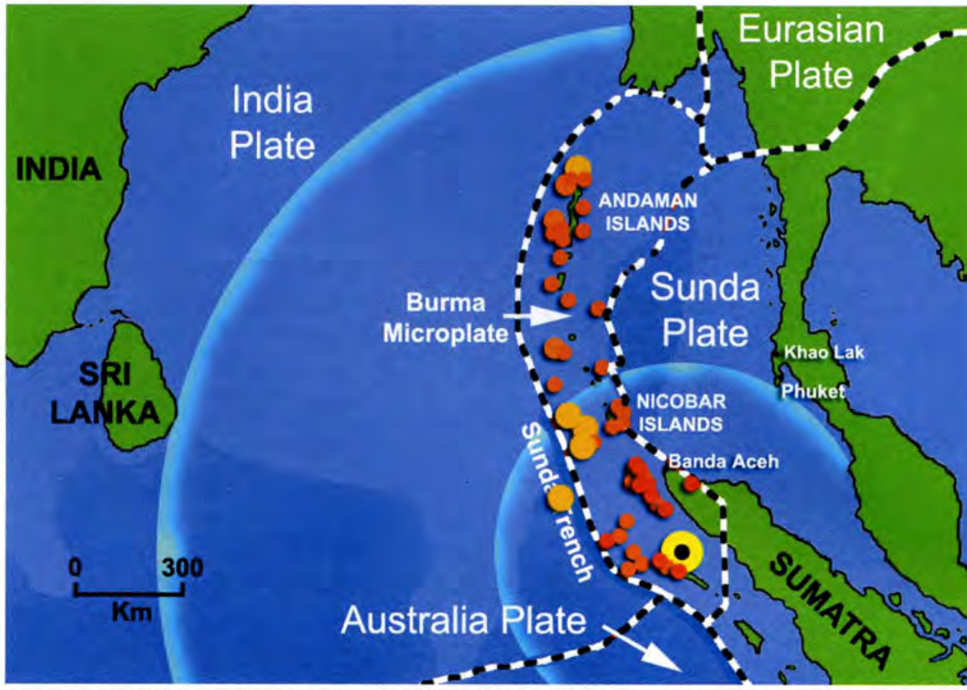

Figure 1: The 9.0 Mw earthquake epicentre is illustrated by a large circle with a spot. The Plate boundaries are marked together with places mentioned in this text and the smaller circles represent aftershocks.

The Banda Aceh earthquake was BIG. It ranked a 9.0 on the Mw seismic scale as the joint-fourth largest earthquake in the last century, rivaling the 9.0 Mw Kamchatka earthquake of November 4th 1952. (The Mw scale is one of four commonly used seismic scales; it reflects the moment of the earthquake that is a measure of the rigidity of the earth times the average amount of slip on the fault times the amount of fault area that slipped). Larger earthquakes include the 9.1 Mw in the Andreanof Islands in Alaska; the 9.2 Mw Prince William Sound (Good Friday) earthquake on the March 23, 1964, and the 9.5 Mw colossus near Valdivia in Chile on May 22, 1960. However, the loss of life was significantly less in each of the other earthquakes. The Chilean earthquake, the largest ever instrumentally recorded, had about 2,800 deaths with less than 250 attributed to the tsunamis that swept across the Pacific to Japan and the Philippines.

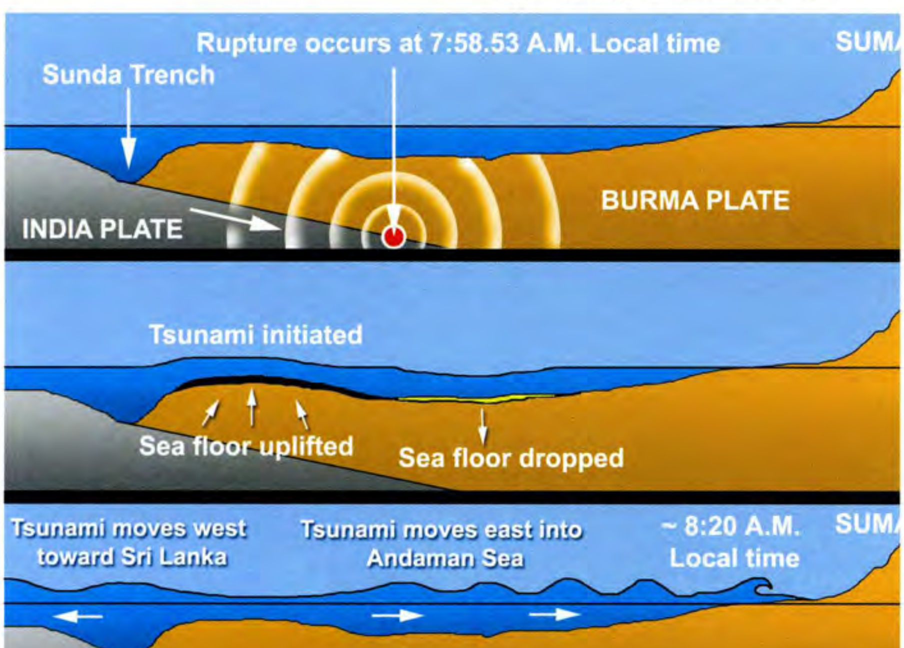

Figure 2: The initiation of the megathrust earthquake and tsunamis. The vertical scale is greatly exaggerated. The average displacement on the fault plane was about 15m over a distance of 100km. The sea floor immediately above was raised about 2m and a smaller area was dropped by a similar amount. The oscillation on the sea surface generated the tsunami waves.

These tsunami "tidal waves" raced toward Banda Aceh and other small coastal communities. The oscillatory motions within the waves travel at high speed - at about 800km per hour - although if you were at sea you probably would not notice the wave passing under you. However, when the waves reached land the water slowed and piled up. At least five huge waves, estimated at 12m in height crashed into Banda Aceh. The devastation from the earthquake (locally estimated at Magnitude 8) and the associated tsunami waves was terrifying and complete as the water surged several kilometers inland (Figure 3). Many people undoubtedly died because they simply did not realise what was happening.

I always tell my students that if they are on the seashore and the water suddenly starts to move rapidly offshore, don't wander down to see flapping fish and pick up shells, just head for the highest point that you can find furthest from the coast, because a tsunami wave is likely to follow. This is exactly what one ten-year old British girl told her mother. She had just finished a school class on earthquakes and tsunamis before going on vacation in Thailand. She communicated this to her mother who alerted Thai staff at their resort

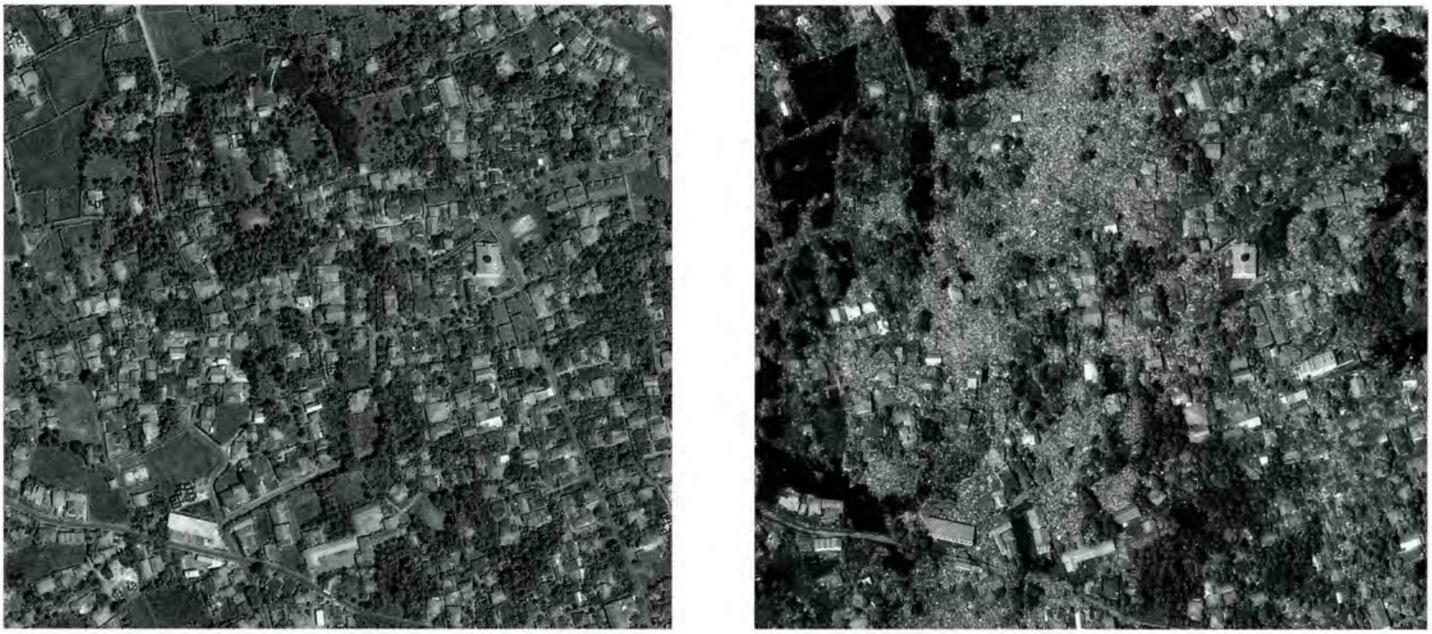

Figure 3: Banda Aceh. A prosperous community on the northernmost tip of Sumatra was the closest large town to the earthquake epicentre. Of the 300,000 residents about 100,000 are believed to have died. The two images above illustrate the scale of the disaster. The images have been cropped and aligned to show the same area. The yellow building with a black spot and the large grey-roofed structure (bottom left) provide reference points. At the top left (left image, taken June 23, 2004) is large, silted, meander loop. In the right image (taken December 28, 2004) this area has been completed filled with debris, likely floating on the water surface. Few building are still standing after this area was rocked by the Force 8 earthquake.

Figure 4: Resort area at Khao Lak, Thailand. Image (left, taken in 2003) shows the resort and pool, a small bridged stream and fish ponds to the west and north. The image on the right shows the same area on December 28, 2004. Note the almost complete absence of vegetation, the almost total removal of beach sands, and the enlargement of the estuary area. Not included in this image is the destruction of the reef area to the northwest. Both images courtesy of DigitalGlobe. Khao Lak was hit by tsunami waves about 2 hours after the earthquake whose epicentre was approximately 650 miles away. Wave heights in this area were estimated at 10m.

and 100 people ran to safety before the waves swept in. Another survivor in Banda Aceh realized that the earthquake would likely be followed by a tsunami. He gathered his wife and two children, put them all on his motor cycle and headed inland until he ran out of gas. They all survived, watching the waves crashing across Banda Aceh from a hillside outside the town. In both cases some basic geological knowledge allowed the survivors a sufficient time interval that they were able to escape.

Detailed satellite images have allowed us to see "before and after" images of many of the areas affected, and it allows us to appreciate the nature of the tsunami and its results in stunning detail. Space precludes presentation of many of the details and I have inserted several that I feel are appropriate. The comparisons are all provided courtesy of **DigitalGlobe "Quick Bird images"**.

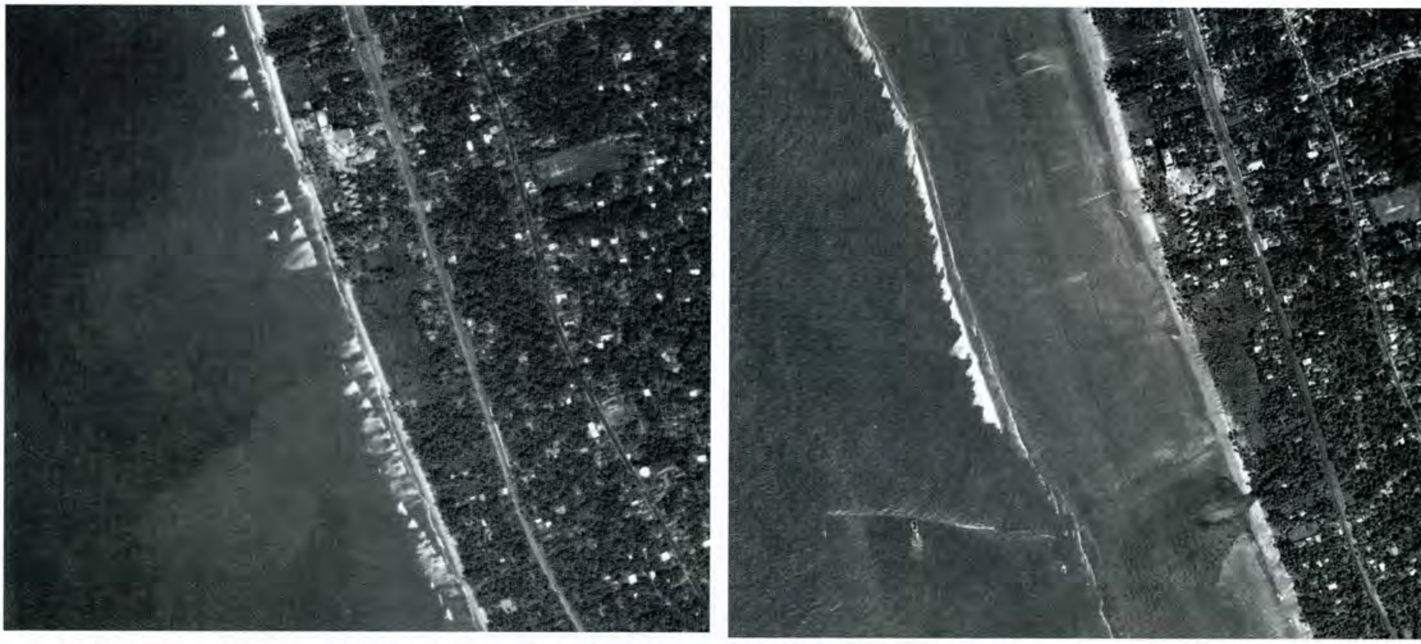

Figure 5: Kalutara beach area about 40km south of Colombo, Sri Lanka showing "normal" tide on January 1, 2004 and the abnormal withdrawal of the sea on December 26, 2004. The cover image illustrates what happened shortly after as the tsunami wave surged into Kalutara. DigitalGlobe images.

Figure 6: The beach at Hambantota, SE Sri Lanka. (left image taken by AVM in January 1995). Note the boats on the beach. Right image (courtesy Plan International) shows the lower area of Hambantota in late December 2004. All the boats were swept into the lower area of the town.

The tsunami waves did not stop on the western coasts of southeast Asia, they also raced across the Indian Ocean and slammed into the coastline of Sri Lanka and southern India. The town of Hambantota was devastated by waves. At least 1,100 are reported dead and 1,000 missing out of a population of about 48,000. Many of the boats in Figure 6 ended up inside the lower part of the town. Similar stories are typical along the northern, eastern, and southern Sri Lanka coastline, where over 30,000 are reported killed with many more still missing. The death toll is estimated at about 15,000 along the southern coast of India. And still the waves rolled on.

The waves were recorded as tidal fluctuations in New Zealand and even along parts of the west coasts on North and South America. As I complete this, more images are coming in of the ravaged coastline of Sumatra. News from my sister is that one of her closest friends and family were killed in Thailand where they had gone for a Christmas vacation.

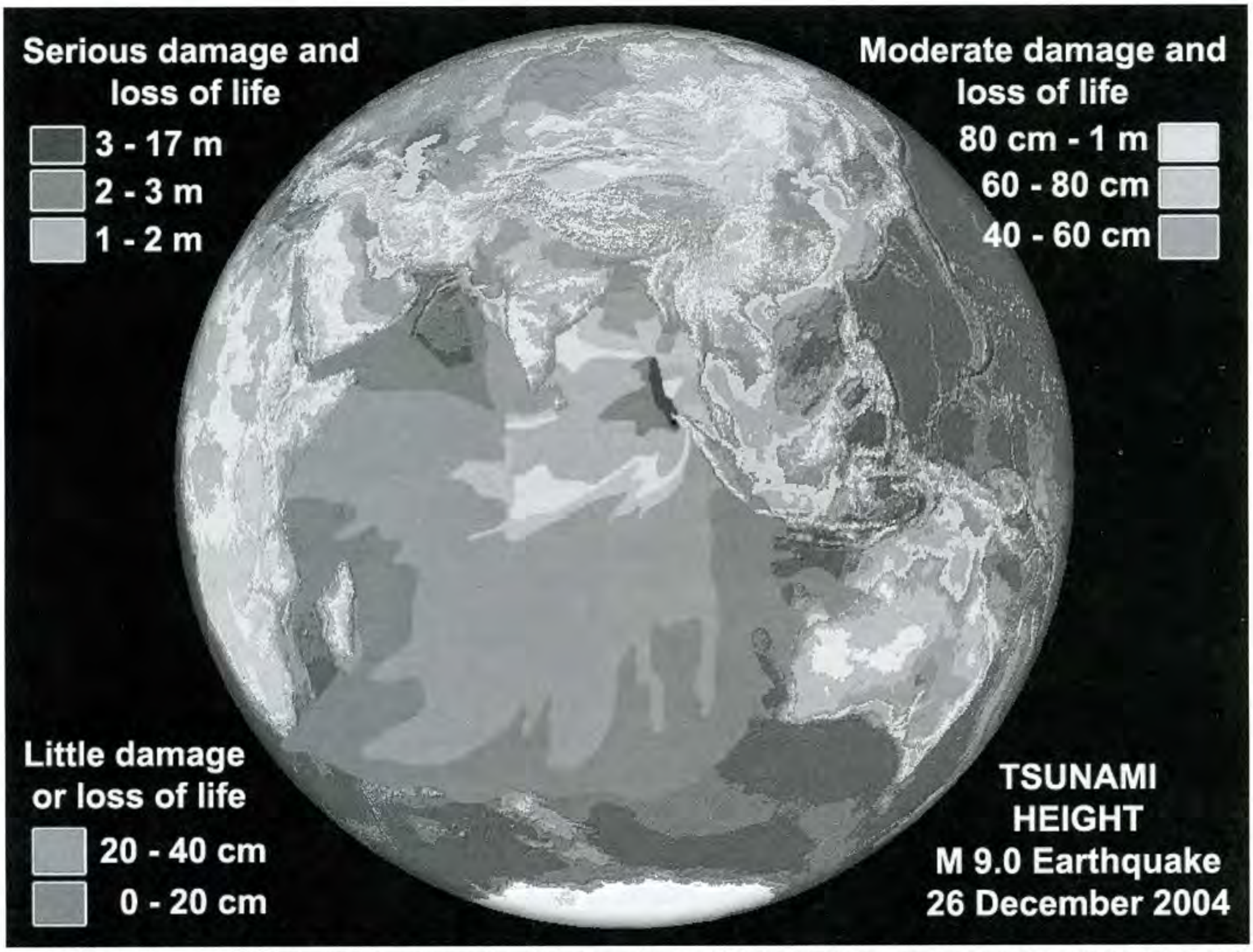

Figure 7: Wave heights generated by the great Sumatran earthquake on December 26, 2004. Areas in darkest grey tones are regions that were worst hit. Note that the waves were attenuated at the Maldive Islands, southwest of India. The waves eventually reached the coastline of Africa where deaths were recorded, particularly in Somalia where at least 150 persons drowned.

This is an event that stunned the world. Geologically we expect this to happen, but it is always a shock when the human side of the disaster is revealed. Politicians are vacillating on how and where aid should be delivered. Three billion US dollars has been donated, and a small fraction of this sum in advance could have established a tsunami warning system for the areas most affected. Likely little could be done for the coastline of Sumatra which was so close to the epicentre of a huge earthquake, but even there people would have had enough warning to escape the waves. Certainly in Thailand, Sri Lanka and India there was sufficient warning to have moved people the few kilometers inland. That would have been enough in Khoa Lak to have saved several thousands. A few simple lessons in basic geology would also have helped. And perhaps the most ironic observation is that less than one month before this disaster the UNESCO decided to close its Division of Earth Sciences.

Alan Morgan

TALC

Duncan Kwok
Peter Russell,
Amy Sittler

The mineral talc is a hydrous magnesium silicate. A massive talcose rock is known as steatite, and an impure massive variety is called soapstone.

The Name Talc

The name talc is believed to be derived from the Arabic word talg or tolk meaning mica, since talc forms mica-like flames. The present name was given by Georgius Agricola in 1546. Kerite is a common name also used for talc.

Uses of Talc

There are many uses of talc, especially as an industrial mineral because of its resistance to heat, acid and electricity. Because of these resistances it can be used as counter tops, electrical switchboards, ceramics, and insecticides. It is most commonly known as the main ingredient in talcum powder. It is also an important filler in paints and rubber. Talc is used commercially because it can retain fragrance, luster, purity, softness and whiteness. Some of the major markets for talc are ceramics, paint paper and plastics. Ground talc is used in roofing, and cosmetics.

Physical Characteristics

Talc can be blue, pale green, gray, pink, white, yellowish or brownish white to almost silver. Its luster is dull to pearly or greasy. What determines these characteristics are its natural or artificial impurities. Talc only has a hardness of one on the Moh's scale of hardness. This translates into a very soft material, which results from its layered nature. Naturally, this substance is hydrophobic (dislikes water), and tends not to absorb water, therefore giving some of its favourable water-resistant characteristics.

Talc and Pyrophyllite

Both of these minerals are nearly identical, each being very soft, talc is one on Moh's scale of hardness, and pyrophyllite is one to two. Both can be easily crushed and cut, because they are so soft. Also both have perfect cleavage in one direction, allowing these minerals to break into thin sheets. Each feels greasy to the touch, this is why talc is used for a lubricant, and both are formed in metamorphic environments.

Substitutes and Alternative Sources

Some replacements for talc when manufacturing ceramics are clays and pyrophyllite. Kaolin and mica can be substituted instead of talc in rubber paint and plastics production. For paper production, kaolin can be used in place of talc. There is an abundance of talc with sufficient amounts for many decades to come, but some of these alternatives may be cost-effective depending on the cost of talc. China is the worlds top producer of Talc followed by the U.S. and Japan.

Canada Talc Mines

Talc was first discovered on a farm in Madoc in the 1880s. It was in 1896 that the Henderson Talc Mine came into production. In 1911 the Conley Mine opened in the adjacent property, where there contained a northeast extension of the Henderson ore body. The mines went through various owners until 1937, when the Henderson and Conley mines were merged into one under the name Canada Talc Limited. Again in 1951 Canada Talc was bought by Canada Talc Industries Limited. More than 800,000 tons of high-grade talc has been mined from this deposit, to date.

To be continued in the next issue.

Fossils

Alan V. Morgan

My first fossil find was, literally, a life-changing experience. I was eight years old, playing with my younger brother and friends when I crawled under a large blackberry bush to hide. In the semi-dark a large snail rested on the ground beside me. Gingerly I gently poked it until it rolled over. It was strangely heavy and I picked it up. My game was over. I rushed home to my mother who told me that what I had found was a fossil snail. She had been brought up in the South Wales coalfield and was used to seeing fossil ferns and plants that were occasionally brought back by members of our mining family.

One week later we went to the National Museum of Wales in Cardiff. Emlyn Evans, the School's Service Officer, to whom I owe a tremendous debt, had

the specimen (Figure 1, above) identified as *Pleurotomaria anglica* (J. Sowerby). It was from the Lower Lias of the Jurassic and about 175 million years old. I was hooked! What was this "thing"? Why did it have a funny name? How had it been turned to stone? How did the geologists at the National Museum know how old it was? What on earth was the "Lower Lias" and the Jurassic? Emlyn invited me to the Saturday morning "classes" conducted by the museum. For two years I traveled back and fore to Cardiff on the local train, being met and returned to the station in Cardiff by Emlyn (the sort of thing that probably would not happen today). I was told that if I wanted to become a geologist I would need a university degree in geology, perhaps even a Ph.D. When, two years later, I moved up to the grammar school system I could see, somewhere on that distant educational horizon, some sort of career in geology. My two geology teachers in Barry Grammar school, A.J. James and Jack Edney are also owed a great debt of gratitude.

Of course, now at the "other end" of my life I simply did not realise what excitement and pleasure that inadvertent chance discovery would provide me. It has taken me to most corners of the world, provided me with challenges and adventures and a constant wonder of this intriguing place that we are permitted to be part of, albeit for a short time. So this brief introduction brings me back to the topic of fossils, a word derived from things that are "dug up" from the Earth.

Fossils and the Geological Past.

Fossils are part of a tangible record of organisms that have inhabited our planet in the distant past. They are defined as **"the remains or traces of formerly living organisms."** When I was starting my geological "career" about half of a century ago, conventional wisdom was that true fossils were confined to the last part of the geological record, from the Cambrian to the present. The vast expanse of geological time (see *What On Earth* V.2; No. 2, pp. 12, 13 and related text) known generally as the "Precambrian", was regarded as unfossiliferous and those fossils that had been reported from Precambrian rocks were generally thought to be of non-biological origin (gas bubbles, concretions and other inorganic features). In fact, we now know that life - albeit in microscopic form - was present back to the earliest times of our planet's history. Our world was subject to intense meteorite and asteroid bombardment from its origins, about 4.56 billion years ago, to about 3.8 billion years ago. When this massive bombardment stopped we see geochemical carbon isotope "signatures" in rocks from Greenland that indicate organic life forms were present. Where these early life forms originated has long been a subject of scientific speculation. Early ideas were that they were produced by electrical discharges in an "organic soup" that prevailed in a primitive reducing atmosphere on Earth. These ideas have more recently been cast into doubt by the realisation that a reducing atmosphere might have been short-lived, and a second explanation, that life might have arrived from space, could be a more attractive alternative hypothesis. We know that complex organic compounds exist in space and might have been transported to our world by comets that plunged into our world's early atmosphere and oceans.

Organisms in our world today belong to three main groups. The first are the eukaryotes (organisms with genetic material contained within a cell nucleus and protected by a cellular membrane), bacteria (single-celled organisms without an internal cell membrane) and "archeobacteria". The archeobacteria and very primitive bacteria are autotrophs; that is they make their own food by a process of "capture and synthesise" by utilising chemical energy outside the organism. We also believe that this took place frequently in the past, perhaps at sites where hot springs and sulphide vents associated early ocean spreading took place in many parts of the early crust. "Real" fossils appear as microscopic filamentous bacteria dated to approximately 3.5 billion years in rock in western

Australia. These are part of a group of organisms that include the cyanobacteria, photosynthesizing algae known as stromatolites. Their modern counterparts survive today in hypersaline ocean water in places like Hamelin Pool in Shark Bay, western Australia. They are rather uninteresting blackened mounds consisting of sheets of algal filaments that have trapped layers of sediment. Hypersalinity helps to protect these colonies from the predation of grazing molluscs, a problem that did not exist back in the Precambrian. Stromatolites are important since their photosynthetic activity helped to create the oxygen-rich atmosphere that is essential to most advanced life forms.

These advanced life forms (eukaryotic cells and metazoans) date back to at least 2.1 billion years, and there are many localities throughout the world that contain different examples. In the last part of the Precambrian animal life started to develop the diversity of forms that we see today. Encysting stages of phytoplankton are recorded at 1.6 to 1.4 billion years. The earliest description of truly diversified metazoans (*Aspidella*) were reported by Elkanah Billings in 1872, from the Avalon Peninsula, south of St. Johns in Newfoundland. Other advanced Precambrian fossils were found in Namibia in 1933, an exceptionally diverse fauna at Ediacara in South Australia in 1946, in Charnwood Forest, Leicestershire, England in 1957 and subsequently in the White Sea Region, in the United States, China, and elsewhere. The oldest dated advanced form is a "giant" metazoan, *Charnia wardi* that is about 575 million years old from the south coast of Newfoundland. Some of these organisms are illustrated in the centrefold of this issue.

It was not until the advent of Cambrian time that the full diversity of fossil life is well seen in the geological record from many different parts of the world. With what appears to be of amazing geological rapidity these 542 million year old rocks are crowded with conventional and bizarre life forms. Some appear as "dead-ended" forms that literally flashed on, and off, the world's stage. Others plodded along until their modern "descendents" appear to be virtually unchanged from their earliest ancestors. I will go on to explore some of the various important fossil groups that we see in the fossil record, but before that we should talk a little about how fossils are preserved.

Figure 2. Precambrian stromatolite colonies, Pilbara, W.A.

Figure 3. Modern stromatolites at Hamelin Pool, W.A.

Fossil preservation

Fossils can be preserved in a multitude of different ways. These depend on a variety of factors that might include;

rock lithology (a reflection of the original sediment in which good preservation shows a preference for fine rather than coarse grained rocks). Consequently limestones, mudstones and shales are better lithologies for preservation than conglomerates, breccias, and coarse sandstones. This, in turn might be a reflection of the original depositional environments since finer sediments are generally present in less energetic environments. Marine and lacustrine sediments are better repositories than most terrestrial environments since erosion and transport generally breaks potential fossil material.

The **nature of the original organism** is important. Large, thick-shelled or heavily armoured organisms will likely preserve better through time than thin and fragile organisms. **Post-mortem and post-depositional events** are important. Shortly after death predation by large and small carnivores, scavengers and micro-organisms can complete destroy potential fossil remains. In a longer time frame fossils can be destroyed by percolating fluids (for example, dolomitisation). These changes are known as diagenetic changes. In still longer time frames metamorphism can stretch and destroy fossils by stress or by heat and pressure as new minerals form.

Assuming that organisms survive these inherent risks there are a variety of modes of preservation. Amazingly, soft parts of fossils can be preserved although this usually requires a very rapid removal of the organism from the destruction of both predators and bacteria. One of the classic methods is by entombing the organism in resin which eventually changes to amber (Figure 4). Fossil insects - shades of "Jurassic Park" - are moderately frequently found in this way and date back at least to late Cretaceous time. On a different scale much larger animals, such as mammoth (Figure 5), bison and horses have been recovered from relatively recent permafrost.

In the youngest parts of the geological column many shells contain the original aragonitic structures that they possessed in life. Further back in time there is a slow alteration of the aragonite to calcite (a more stable

Figure 4. Small fly trapped in amber, Baltic region.

Figure 5. Baby mammoth in melting permafrost, Siberia.

configuration). Shell or plant materials can be replaced on a cell-by-cell basis by other minerals carried through percolating fluids that migrate through sediments and rock sequences. Classic examples of replacement may be by silica, by pyrite, or by iron carbonates such as siderite. In the case of plant materials (and less so in the animal kingdom) the change is by carbonisation. Here the volatiles in the organism are gradually driven off finally leaving a film of carbon that often preserves quite delicate structures from the original plant or animal. Examples of each of these preservational modes are shown in the centrefold pages.

Figure 6. Australian dingo, Canis familiaris.

Classification of fossils.

The modern system of classification dates back to 1758 when Carolus Linnaeus devised a binomial classification for animals and plants. Today we still used a modified form of this system. I tell my students to remember the gnomonic, Kind People Care Only For Giant Slugs, where the initial letter stands for the major elements of the classification, i.e. Kingdom, Phylum, Class, Order, Family, Genus, Species. For example the animal illustrated on the left (Figure 6) is an Australian dingo. The full classification of the dingo would be: **KINGDOM Animalia;** (Sub kingdom) Metazoa; **PHYLUM Chordata;** (Sub phylum) Vertebrata; (Super class) Tetrapoda, **CLASS Mammalia;** (Sub class) Theria; (Infra class) Eutheria; (Cohort) Ferungulata; (Super order) Ferae; **ORDER Carnivora;** (Sub order) Fissipeda; (Super family) Canoidea; **FAMILY Canidae;** (Sub family) Caninae; (Tribe) None; **GENUS Canis;** (Sub genus) None; **SPECIES *Canis familiaris*;** (Sub species) None. (whew)! The common name is "Dog", and you might further differentiate it as a "Dingo", rather than a "Poodle" or a "Pit Bull", or a "Chihuahua". In fact there are over 400 varieties of dogs, but they all have two things in common - they all can interbreed, and produce viable offspring (the definition of a species) - and all are *Canis familiaris*. It is important to use the Latin classification because confusion can arise by using "common" names. For example the term "Robin" means completely different birds to a North American versus a European. The "robin" of North America is a moderately large orange-breasted bird whose Latin name is *Turdus migratorius*. The European "robin" is also an orange-breasted bird, but is much smaller, and its Latin name is *Erithacus rubecula*.

When we look at fossils we have some problems. We have to work with limited information and we have unknown variables, especially if the species has been long extinct. However, we can work with some basic scientific assumptions and we are constantly refining identifications, which is why there is a major scientific furor when new fossils are found, or "living fossils" - like the Coelocanth - turn up after being "absent" from the geological record for millions of years. We do try to follow the Linnaean classification which is why "my" snail is *Pleurotomaria anglica* (J. Sowerby). *Pleurotomaria* is its generic name, *anglica* is its specific name and J. Sowerby was the person who named it. The rest of the classification precedes it, right back to the "Kingdom" level. I might mention that there are five currently accepted "Kingdoms" that all things fall into. These are **MONERA** (All Prokaryotes, and bacteria); **PROTOCTISTA** (Protozoa, slime molds, n.algae); **FUNGI** (also Lichens); **PLANTAE** (all Eukaryotic plants) and **ANIMALIA** (all Eukaryotic animals).

The reality of fossil preservation

Most of the fossils that have been illustrated above and in the centre pages are examples of "better than average" preservation. There are different localities in the world where excellent fossil preservation is not unusual; however, the majority of fossils are of "average" preservation, and usually result from being "internal" or "external" molds. These are formed in the following way.

Figure 7. Three diagrams illustrating (left to right);

1). A clam (pelecypod) in growth position. Sediment is falling to the sea floor.

2). The clam has died. Sediment has completely entombed it and the sediment has lithified to rock. The interior of the specimen has filled with sediment but the shell is still intact and the sediment (internal and external) has preserved the morphology of the exterior and interior of the shell.

3). The rock that entombed the (now) fossil shell has been involved in tectonic activity. Stress has distorted the shell morphology in this mildly metamorphic rock type.

Figure 8. The lower two rows illustrate how an internal cast – (middle line) and external cast – (bottom line) is formed as a fossil weathers from rock.

The photograph shows two clams that illustrate both forms.

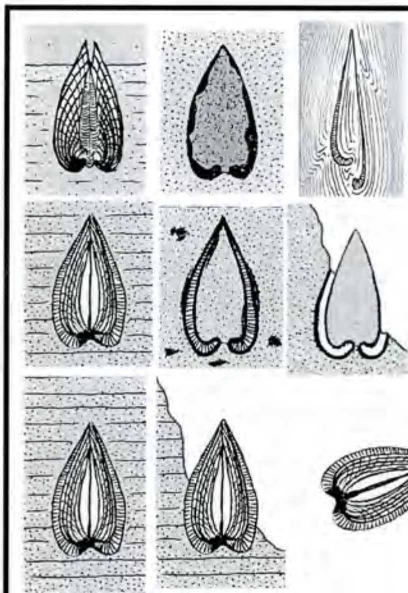

Figure 7.

Figure 8.

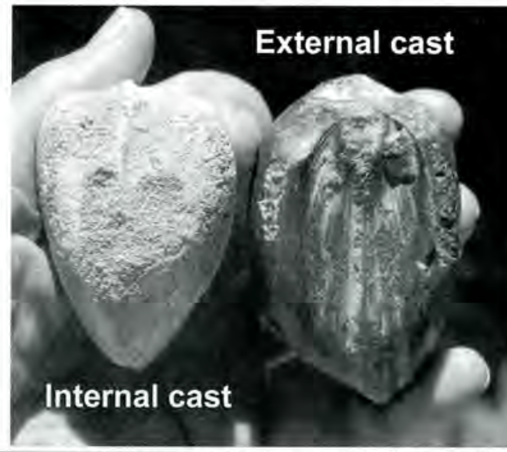

Figure 9.

Fossils: An explanation of the centrefold images

A moderate amount of explanation is required for the centrefold. First let me say that all specimens (with one exception) are "real" fossils. The images are all copyright of the author, (except *), and a number are from my personal collection. The specimen sizes (not illustrated) vary considerably and range from microfossils to organisms that are up to about 10 m in length.

The central part of the image represents the geological time scale. This has been explained in moderate detail - including time boundaries - in the last issue of What On Earth (Spring Issue, 2004). Fossils have been present in the geological record almost back to the start of Earth's history, but the vast bulk of geological time is not well represented in this diagram. Instead I have concentrated on illustrating three images from the "earlier" part of the Precambrian, and another three from the "youngest" part of the Precambrian record. Most of the images (7 to 28) are fossils from the Phanerozoic Eon, the youngest part of the column when life forms proliferated in numbers and diversity. The Phanerozoic is split into the Paleozoic ("Ancient Life" - images 7 to 15); the Mesozoic (" Middle Life" - images 16 to 25) and the Cenozoic (" Recent Life" images 26 to 28). The "life positions in time" of each of the fossils is illustrated by a corresponding number on the Geological Time scale. These are relatively accurate but generalised.

Deciding on what images to introduce was also difficult. These are not all Canadian examples, although many representatives would have close relatives present in the various rock sequences across Canada. The bulk of the illustrations are all Eukaryotes. These include invertebrates (Animalia), but a number are vertebrates (also Kingdom Animalia) a few are plants (Kingdom Plantae) and several Prokaryotes represent the Kingdom Monera. The Kingdom Protoctista is illustrated by one image, and the only Kingdom not represented is the Fungi.

I have tried to illustrate forms that are relatively common and many of these are used as zonal fossils. I have also tried to illustrate very general lineages

Continued on page 15

A Visit to the "Temple" of Serapsis at Pozzuoli


Frontispiece: Lyell's "Principles of Geology."


"Temple of Serapsis", August 2004.

One of my most treasured books is a first edition of Lyell's *"Principles of Geology (being an attempt to explain the former changes of the Earth's Surface - by reference to causes now in operation)."* Published in 1830 - in two volumes, although a third was added an 1833 - this was the same edition that Charles Darwin took with him on his round the world voyage of the *Beagle*.

When you open the book the frontispiece is an intriguing woodcut by T. Bradley, entitled "Present state of the Temple of Serapsis at Puzzuoli." This summer I was finally able to get to the so-called "Temple" of Serapsis on the western edge of Naples. Why should such a building be of interest to geologists? Lyell (quoting a Signor Carelli) pointed out in his text that the building was nether a "temple" nor was it devoted to Serapsis (since worship of this Egyptian God had been prohibited by the Roman Senate). Lyell concentrated instead on the "legible characters (inscribed) by the hand of nature" that are preserved on the columns.

"The pillars are forty-two feet in height (12.8m); their surface is smooth and uninjured to the height of about twelve feet (3.66m) above their pedestals. Above this is a zone, twelve feet in height, where the marble has been pierced by a species of marine perforating bivalve - *Lithodomus*, Cuv." Lyell goes on to remark on the numbers of holes and the remains of the molluscs that were still preserved *in situ*. He further points out that "the platform of the Temple is at present (in 1828) about one foot below high-water mark…" From these observations he concludes that the upper part of the perforations (formed by marine molluscs) are at least twenty-three feet (7m) above high-water mark. Finally he correctly elucidates that since "…the temple could not have been built originally at the bottom of the sea, it must have first sunk below the level of the waves, and afterwards have been elevated." The lack of molluscan borings in the lower part of the pillars he attributed to sediment and building debris covering approximately the basal 3.5m. To support subsidence and re-emergence in the region Lyell mentions that nearby there are ruins of the Temple of the Nymphs, the Temple of Neptune and two Roman roads under water. In a most enlightened statement he comments that "(People) will be very much astonished if future researches fail to bring to light similar indications of change in all regions of volcanic disturbances."

That brings me to my visit in 2004 on one of the field trips of the 32nd International Congress. We spent a little while at the small park in Pozzuoli that now surrounds the "Temple of Serapsis", as part of a journey that looked at some of the volcanic hazards of the Naples area. Unfortunately you cannot descend to walk on the pavement as Lyell did in 1828, hence my images above are not precisely matched. However, you can make some additional observations. The floor of the "temple" - now re-interpreted as a market place - is relatively dry. The port facility, barely a hundred metres away, has had some considerable problems in recent years because the harbour floor is rising at a remarkably rapid rate.


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19,20
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Paleozoic
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14
CA
12,13
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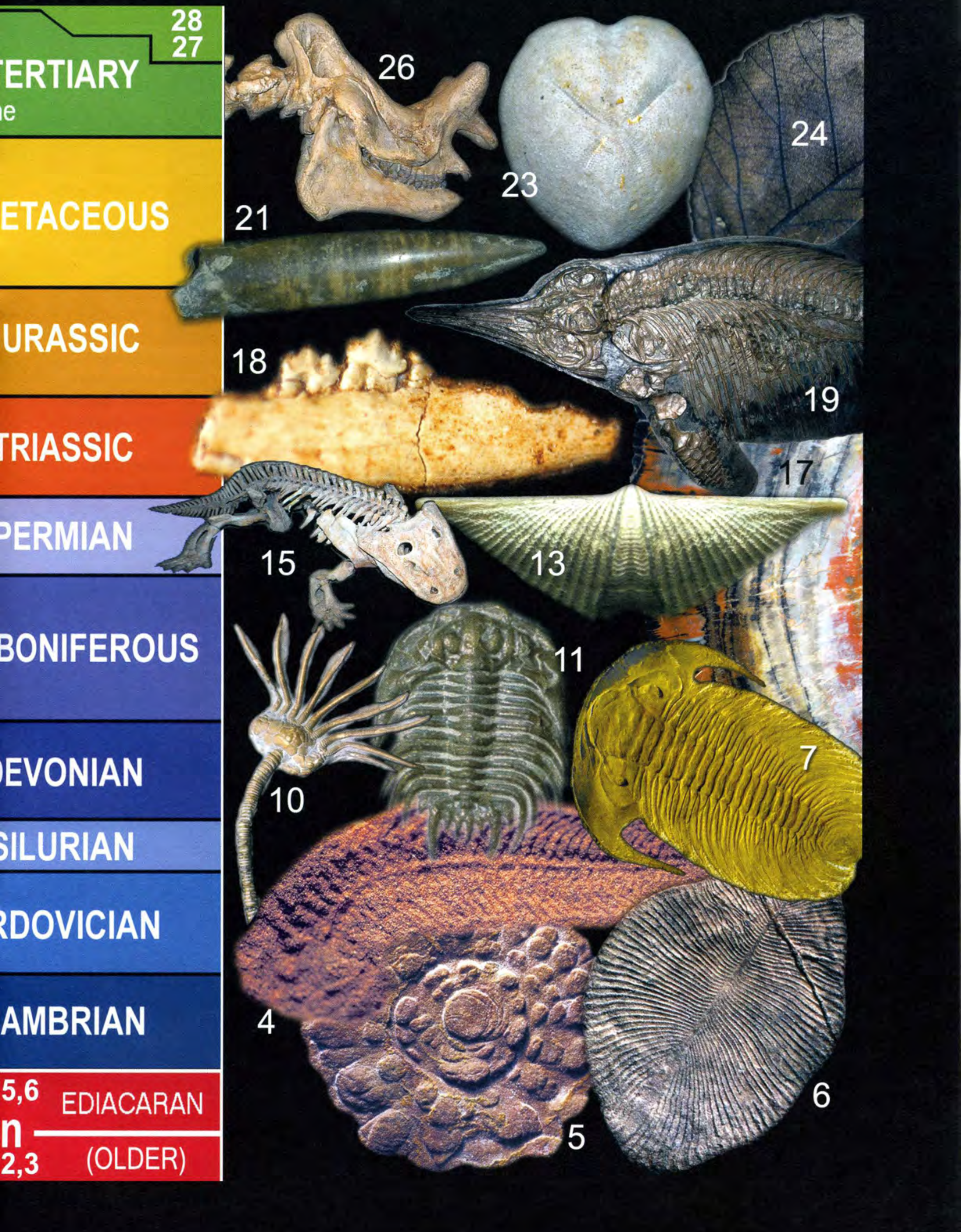
Precambr



28
27
TERTIARY
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ETACEOUS
URASSIC
TRIASSIC
PERMIAN
BONIFEROUS
DEVONIAN
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AMBRIAN
5,6
EDIACARAN
n
2,3
(OLDER)
26
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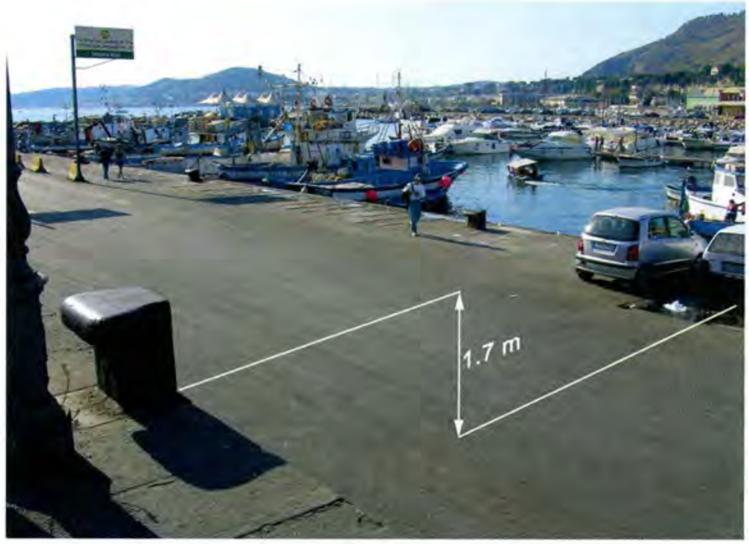
The harbour at Pozzuoli.

Boats used to moor here until quite recently. A line of bollards have been left "high and dry" on the old, elevated, quayside. A new roadway has been constructed below with a second line of mooring bollards (adjacent to person walking in the centre). The drop from the old surface to the roadway is indicated.

This area has experienced several episodes of uplift since 1970 and the elevation of the harbour floor is an indication of this gradual ground inflation.



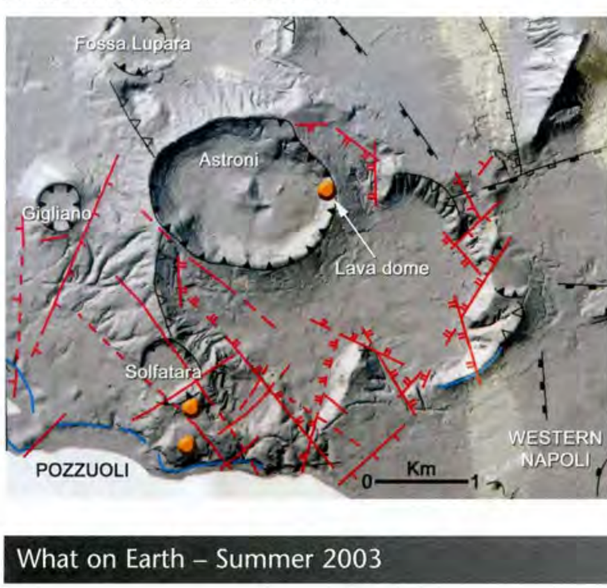
Why were we visiting this area and why should these "ups and downs" of the land be a matter of concern? The Pozzuoli region is subject to small earthquake swarms that accompany land inflation and deflation. The area is volcanically active with three volcanoes, Solfatara, Astroni and Monte Nuevo, being active over the last four thousand years and the latter having erupted on September 29th, 1538. What is of even more concern is that these two vents are part of a far larger caldera complex known as Campi Flegrei, or "The Phlegreaean Fields".

Does this area have the potential to erupt again? Looking at the geological evidence I would find it very hard to say "no". The Campi Fleagri caldera has a long (~ 50,000 year) history of eruptions including two catastrophic ignimbrite (glowing avalanche) flows. One of the earliest, some 37,000 years ago, ejected the Campanian Ignimbrite (approximately 150 km^3 that spread over 30,000 km^2) and the second, some 12,000 years ago, deposited the Neopolitan "yellow" tuff from an eruption of some 50 km^3 that covered about 1,000 km^2. Since that time there have been large eruptions from various centres at 10,300, 9,500, 8,600, 4,800, 4,100, and 3,800 years B.P. The 1538 Monte Nuevo eruption that was preceded by major ground inflation followed a 3,000 year episode of quiescence.

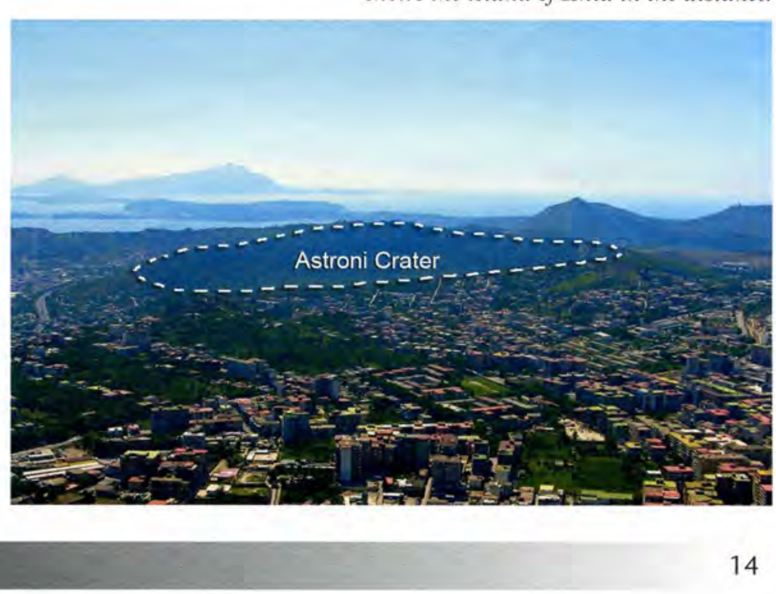
Does the present ground inflation indicate that an eruption is imminent in this area? The Italian authorities point out that the two periods of inflation during the past three decades have been separated by deflation, and the rapid inflation of 4 m seen prior to the 1538 eruption has not yet been experienced. However, bearing in mind the tremendous population growth of this part of Italy, over two million people could be potentially affected should Campi Fleagri enter another eruptive phase. This is a matter of significant concern to the Italian Civil Defence Authorities, especially since estimates for evacuation indicate that at least one week would be required. And of course Campi Fleagri is only on the west side of Naples. In many ways a similar, and yet quite different volcanic threat awaits on the east side of Naples; - that of the Somma - Vesuvius centre, and the subject of another article in the next issue of What On Earth.

Alan V. Morgan.

A digital elevation map illustrates some of the Caldera and eruptive features north of Pozzuoli. Drop faulted areas and lava domes are shown.



View over the southern part of Campi Fleagri. The Astroni crater can be seen in the middle centre. The view shows the island of Ishia in the distance.



through a number of images (i.e. amphibians to reptiles to mammals). However, given the space allocation I apologise in advance for not being more comprehensive. The following is a brief description of each of the fossils. E. is Early, M. is Middle and L. is Late (early being the oldest); BY = Billion Years, MY = Million Years.

1: Stromatolite Cyanobacteria (Pilbara, W. Australia) E. Precambrian, about 3.5 BY. Top view 10cm.

2: Unicellular prokaryotes (Bungle Bungles, W. Australia) M. Precambrian, 1.6 BY. Microns across.*

3: Stromatolite Cyanobacteria (Belt Series, Montana) L. Precambrian, ~ 1BY. Side view 15 cm.

4: *Spriggina floundersi*. Early annelid? (Ediacara, S. Australia) Ediacaran ~ 550 MY. ~30 mm exposed.

5: *Mawsonites spriggi*. Likely Cnidarian (Ediacara, S. Australia) Ediacaran ~ 550 MY. ~ 70 mm.

6: *Dickinsonia costata*. Likely early annelid (flatworm) (Ediacara, S. Australia) Ediacaran ~ 550 MY. ~ 15 cm.

7: *Paradoxides* sp. Trilobite (Morocco) M. Cambrian. ~ 515 MY. ~ 22 cm.

8: *Anomalocaris* sp. Lobopod? (Burgess Shale, BC). M. Cambrian. ~ 505 MY. ~ 75 cm (model).

9: *Didymograptus murchisoni* Graptolite (Abereiddy Bay, Wales) L. Ordovician. ~ 475 MY. ~ 10 cm.

10: Echinodermata (Crinoid) sp. unknown. (Dudley, Worcs, UK.) Silurian ~ 427 MY. ~ 20 cm.

11: *Acidaspis deflexa* Lake. Trilobite (Dudley, Worcs. UK) Silurian ~ 427 MY. ~ 25 mm.

12: Cephalopoda (Goniatite) - sp. unknown; early ammonoid. (Morocco). Devonian ~ 400 MY. ~ 28 cm.

13: *Mucrospirifer arkonensis* Brachiopod (Arkona, ON) Devonian ~ 395 MY. ~ 45 mm.

14: Fern frond (sp. unknown). (PA, USA) U. Carboniferous. (Pennsylvanian), ~ 310 MY. ~ 20 cm.

15: *Eryops* sp. Amphibian. (Loc. unknown, TX, USA) Permian. ~ 275 MY. ~ 3 m.

16: *Kueichousaurus* sp. Reptile. (Loc. unknown, China) Triassic. ~ 247 MY. ~ 2 m.

17: *Araucorioxylon* sp. Fossil log. (Petrified Forest region, AZ, USA) Triassic. ~ 225 MY. ~ 80 cm.

18: *Morganucodon* sp. Early mammal jaw and teeth. (S. Glam, Wales.) Triassic. ~ 203 MY. ~ 4 mm.

19: *Stenopterygius* sp. Marine reptile, Ichthyosaur. (Germany) Jurassic. ~ 195 MY. ~ 5 m.

20: *Asteroceras obtusum* (J. Sowerby) Ammonite. (Lyme Regis, UK) Jurassic. ~ 190 MY. ~30 mm.

21: *Acrocoelites* sp. (Belemnite). - sp. unknown. (loc. unknown, UK) Jurassic ~185 MY. ~12 cm.

22: *Quenstedticeras* sp. Ammonite. (Saratov, Volga R. Russia) Jurassic ~ 160 MY. ~ 40 mm.

23: *Micraster coranguinum* (Leske). Sea-urchin. (Nr. Rochester, Kent, UK) Cretaceous. ~85 MY. ~ 25 mm.

24: Leaf impression. sp. unknown. (loc. unknown; AB, Canada) Cretaceous. ~ 67 MY. ~ 60 mm.

25: *Tyrannosaurus rex*. Terrestrial reptile; Dinosaur. (Dinosaur Prov Park, AB) Cretaceous ~ 66 MY. ~ 2 m.

26: Brontothere. sp. unknown. Mammal. (Cypress Hills, SK) Oligocene ~ 30 MY. ~ 2 m.

27: *Pecten* sp. (Mollusc - pelecypod - clam). (C. Florida) Pleistocene ~ 120,000 years. ~ 12 cm (wide).

28: Echinodermata (sea urchin) 80 Mile Beach, W. Australia. Modern specimen. ~ 5 cm.

Some potential exercises with students.

Using the centrefold chart, ask if they can identify any of the fossils present. Why can they do so? What do they know about them? How old do they think they are?

What fossils do they think are related to one another? (i.e.11 and 8? 12, 20, and 21? 23 and 28?). Why?

Are there any fossils represented that they think are alive today? (i.e.14, 24, 27). Why?

Using a corridor in the school, perhaps reproduce and place specimens according to the geological time scale for the last ~600 million years (Specimens 4 to 28). Corridor should be measured and a suitable scale found to place the images.

Perhaps some of these fossils can be found locally. If so, ask the students what the ages of local rock sequences might be.

Geological Mapping Exercise
Badminton Court Lay-out

A Teaching Tool for Earth Sciences Education
John Etches, Environmental Educator

The focus of this teaching tool is to foster an understanding of the scientific approach to the interpretation of the Earth's history and, therefore, provides insight into the discipline of geology.

The exercise itself takes about one hour to conduct and requires a badminton court with regulation boundaries. Students perform mapping of an idealized geological terrain and utilize simple deduction to interpret observed data. Accurate data collection and application of geological knowledge leads to a reconstruction of a correct sequence of geological events. Coupled with pre-activity and follow-up discussion, this activity can assist in satisfying a great number of expectations within a number of Ontario Ministry of Education curriculum documents, specifically ;

Science Grades 11 and 12; Earth and Space Science, Grade 12, University Preparation (SES4U)

Science and Technology Grades 1-8; *Earth and Space Systems, Grade 7, The Earth's Crust*

History and Geography Grades 7 and 8, Grade 7 Geography
The Themes of Geographic Inquiry
Patterns in Physical Geography
Natural Resources

Through this exercise, students will directly witness how the application of knowledge can result in the valid interpretation and understanding of observed phenomena. The importance of geological mapping and the correct identification of rocks and minerals in the interpretation of the Earth's history is specifically brought to light.

THE IMPORTANCE OF IDENTIFICATION & INTERPRETATION OF ROCKS & MINERALS

The correct assignment of names to rocks is much more than just a matter of interest. The ramifications of an incorrectly named rock are quite serious indeed. The names of rocks tell of their mineral content, texture and how the rocks formed. An incorrect name represents false conclusions drawn about all of the above. It may lead to a misinterpretation of a piece of the earth's history!

Also, once a rock is named, the name may be used in reports, journals and maps. People referring to these geological documents trust the information to be as correct as possible. Geologists and prospectors can infer a good deal of information about a rock just by learning what it has been called. But if a rock type is wrongly named, a false impression of the rock is set forth. The usefulness of the map or report will be questionable.

The purpose of the following is to illustrate the importance of identifying and interpreting the rocks correctly. Closely linked with the identification of rocks is a procedure known as geological mapping.

Geological Mapping and Economic Mineral/Rock Type Associations

The most important phase of any mineral exploration endeavour is geological mapping. It represents the foundation upon which all other exploration work is conducted. The basic function of geological mapping is to identify the geology or rock types present in a given area. This includes showing as accurately as possible the trace of the boundaries between the different types of rocks. But why is it so important to know what rock types are where?

Through years of observation and study it has been found that there is often a definite association between concentrations of economic minerals and the rock type in which they are situated. Occurrences of certain valuable minerals have repeatedly been found in the same type of rock regardless of geographic location. Some economic minerals, such as diamond, occur in one specific type of rock. Diamonds have been found in a rock type called kimberlite. This is a rare type of igneous rock which has crystallized at very high temperatures and pressures. Being able to establish this <u>economic mineral-rock type association for</u> a valuable mineral is an extremely powerful observation. Here lies one of the reasons why geological mapping and the correct identification of rock types is so important.

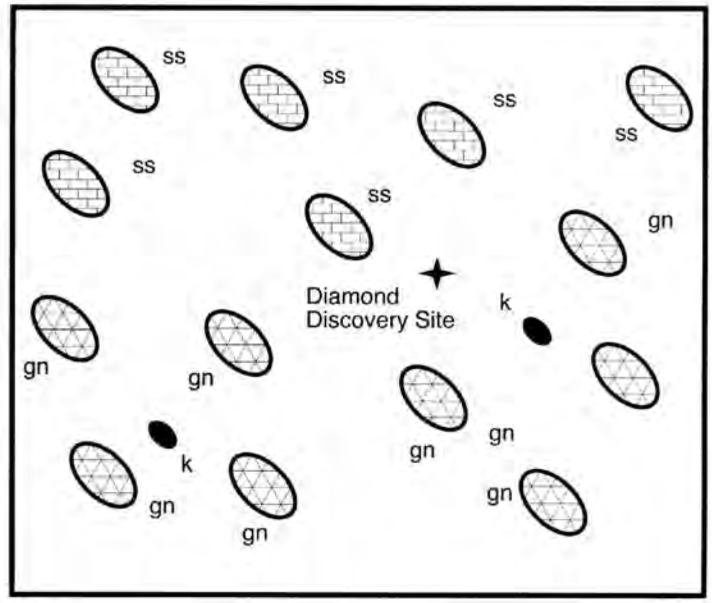
The search for new mineral resources is truly a "needle in a haystack" undertaking where a concentration of valuable minerals may or may not be evident at the earth's surface. Also, surface expressions are often of little assistance as they are usually of limited spatial extent. The establishment of an economic mineral-rock type association aids in reducing an area of search by identifying the most probable rock type and excluding all others. Geological mapping will locate the favourable rock type, if it is present within the area being explored. Once found and isolated, the search can concentrate just within the smaller area occupied by that rock type only. The rocks occupying the surrounding ground can be ignored being recognized as improbable hosts of the minerals being sought after.

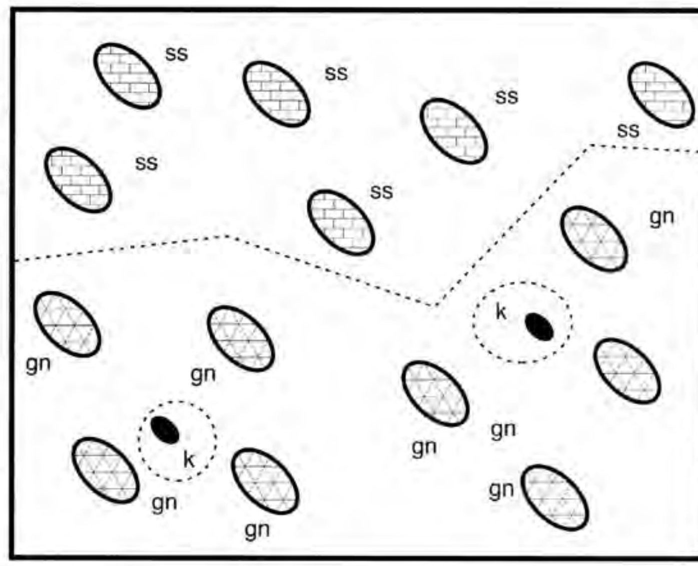
As an example, an imaginary exploration company, Minorex Resources, has decided to explore for diamonds. Attention has been drawn to a particular area since a single, loose diamond crystal was found by a little girl playing in the gravel of an abandoned pit. A 5 kilometre by 5 kilometre area is chosen to be explored approximately centred around the discovery site. The goal of the project is to find the bedrock source of the diamond. Initially, all the company has are maps showing the terrain, lakes and rivers. Within this area of 25 square kilometres, where do they begin to look?

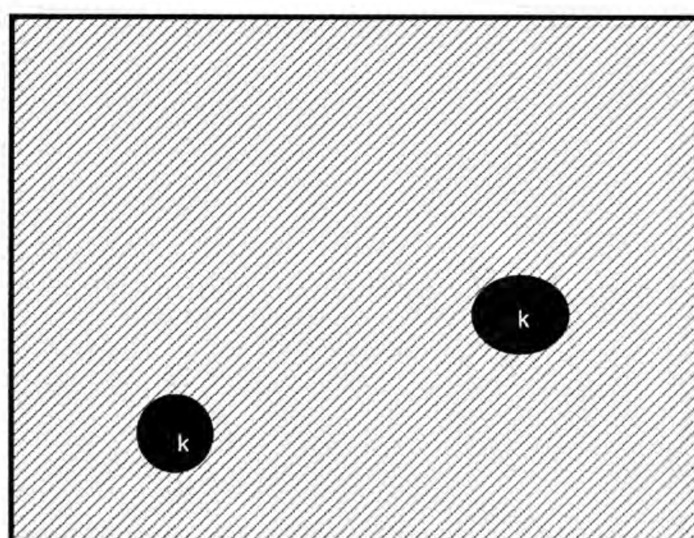
The company's geologist is wise and decides to first map the geology of the area by examining the rock types in outcrops. After days of field work, all or most of the outcrops have been located and evaluated by the geologist. The position of each outcrop is plotted on a base map. Using lakes, rivers and topographic features as reference points, the outcrops can be plotted with a good degree of certainty.

The geologist has identified three types of rocks outcropping within the map area, sandstone **(ss)**, gneiss **(gn)** and kimberlite **(k)**. With the locations and rock types of the outcrops plotted on the map, decisions can now be made regarding where the boundaries or contacts between the different rock types are situated. Remember, outcrop is just where underlying bedrock pokes through soil and other overburden cover. If two outcrops of the same type of rock are separated by an area covered by soil, it is safe to assume that the bedrock under the soil is also of that rock type. If there is no evidence to suggest otherwise, this is an acceptable assumption. But if the two outcrops are of different rock types, then there must be a geological contact between the outcrops where the two rock types meet.

This exploration project has already met with good fortune because the geological mapping has revealed the presence of two kimberlite bodies in bedrock. They are surrounded by a metamorphic rock called gneiss. The remainder of the map area is occupied by a sedimentary rock called sandstone. The data collected by the geologist presented in the geological map above shows the







location and boundaries of each rock type.

Diamonds have never been found in sandstone or gneiss. They are considered unfavourable for the occurrence of diamonds. For this reason, the area underlain by these two rock types can be ignored. All of a sudden, the area of search is reduced to a small fraction of the original 25 square kilometres. An exploration target has been defined.

The success of this phase of the project has hinged on an ability to correctly identify the different rock types present within the area. Without proper identification skills, the kimberlite may have been missed or, even worse, disregarded.

Geological Interpretation

A tremendous variety of information over and above just identification can be derived from each and every outcrop. The map accompanying this text will serve as a simple example showing the kind of information that can be read from the rocks. The example again highlights the economic incentive for interpreting the rocks correctly.

The geologists of an exploration company are confronted with an interesting problem. Minor gold mineralization has been found in a pegmatite dyke exposed in Outcrops 10 and 14 (Dyke A). In the hope of finding a more extensively mineralized zone another pegmatite dyke identified in Outcrops 17 and 21 has also been sampled. This dyke (Dyke B1) which is apparently mineralogically and texturally identical to the one containing the gold mineralization, contains not even trace amounts of gold. How can two dykes so close together that appear to be the same rock type be different? The question of whether or not to continue spending time and money analyzing samples from Dyke B1 becomes an important one. The geologists decided to spend a day mapping the ground adjacent to their study area. It is hoped that other differences (or similarities) between the two dykes will become evident.

After a thorough day's worth of mapping, many interesting features have been found. A third rock type has been identified. A third dyke has been found. A fault has been recognized. With all the outcrops plotted on the map, some geological assumptions can be made.

First of all, the boundary between the newly found sandstone and the granite can be drawn. Looking at the rock types in each outcrop, it can be deduced where the two types of rocks meet. Outcrops 3 and 16 actually show the contact. Outcrop 16 holds another interesting piece of information. Dyke B2 extends up to the contact between the sandstone and the granite but does not cross into the sandstone. This simple fact makes the age relationships between the sandstone, granite and the dyke very clear.

First of all, between the granite and the pegmatite of Dyke B2, which must be younger? Because the dyke is igneous forming from hot fluids invading a crack or fissure in the granite, the pegmatite must be the younger of the two. This is called a cross-cutting relationship.

Dyke B2 is observed to not cross into the sandstone. This shows that the sandstone was emplaced after the dyke was introduced. If the opposite were true the dyke would cross-cut the sandstone as well as the granite. Using these observations, the relative ages of these three rock types is known. The order from oldest to youngest is granite, pegmatite (Dyke B2) and sandstone.

The geological mapping has also revealed the presence of another pegmatite dyke that cross-cuts the sandstone. Compilation of the geologist's data on the map shows that this is a continuation of Dyke A connecting Outcrops 7 and 4. With this knowledge it is apparent that a major difference exists between Dyke A and Dyke B2. The cross-cutting relationship between Dyke A and the sandstone says that the pegmatite of Dyke A is younger than the sandstone. But it is also known that the sandstone is younger than the other pegmatite and the granite. The order from oldest to youngest for all four identified rocks must then be granite, pegmatite (Dyke B2), sandstone, and pegmatite (Dyke A). By just looking at the positions of the rocks with respect to each other, it has been found that the two pegmatite dykes are not of the same age at all.

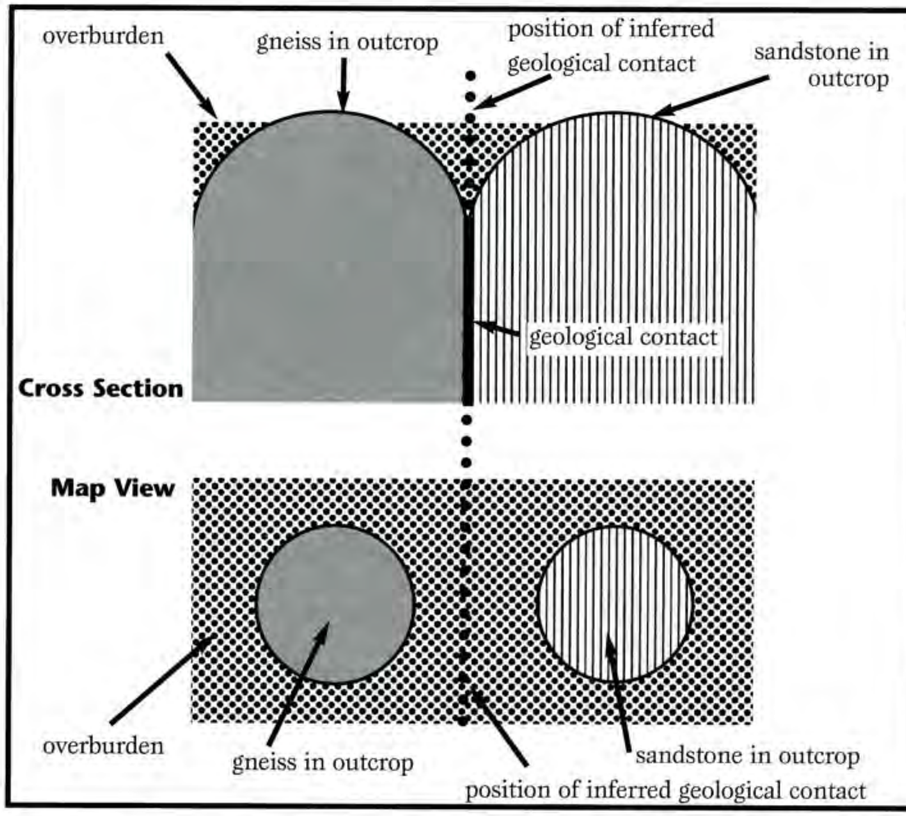
From the mapping of the entire area, Dyke B1 and Dyke B2 can also be interpreted to have been off-set or faulted. These two dykes were originally the same dyke. The shifting of Dyke B1 and Dyke B2 is mimicked by the sandstone/granite boundary showing the same shift direction and amount of off-set.

Dyke A on the other hand appears to cross the fault without being dislocated or faulted. This means that the faulting had to have occurred after Dyke B was introduced but before Dyke A was emplaced. The two dykes, again, cannot be of the same age.

It is possible that millions of years passed between the emplacement of the two dykes. The "parent" igneous fluids which formed the two dykes may have come from two completely different sources within the earth. With this new evidence, it is not surprising that the dykes differ in their gold content. Chemically, they are probably different in many other respects.

With definite evidence that the dykes do not share the same history, the exploration company decides to concentrate on the younger of the two dykes (Dyke A) where the gold mineralization is known to occur. Geological mapping and correct interpretation of the rocks provided the information needed to make this decision.

This example of geological mapping is the basis of the indoor mapping exercise which can be performed by students at any school with a regulation badminton court. Students plot on graph paper the position of mock outcrops laid out on the auditorium floor as shown by the outcrop pattern diagram. The position of geological contacts, dykes, the fault and the age relationships of the rock types can all be interpreted by the student by plotting the outcrops accurately. The exercise serves as a concise and illustrative example of the value of geological mapping.



Geological Mapping Exercise Badminton Court Lay-out

Set-up Time: 10-15 minutes

Requirements: badminton court with regulation boundaries, set of outcrop cut-outs, exercise worksheets, clipboards or notebooks, pencils with erasers

Activity Duration: 1 hour

Set-up Instructions

NOTE: For ease of lay-out, all cut-out positions are at boundary intersections or mid points between intersections as per Sheet #1.

1) According to the pattern given on Sheet #1, lay out all **granite only** and all **sandstone only** outcrops first. They are generic; any sandstone cut-out can be placed at any location requiring a sandstone outcrop, and the same for the granite. This will allow you to place 17 of the 27 cut-outs in less than 5 minutes.

2) Lay out the outcrop cut-outs that are all pegmatite only (all black). There are just two of these.

3) There should now only be eight cut-outs left to place. These should all contain two or three rock type patterns in each cut-out.

Important; ensure that the angles of all **rock type contacts** on the cut-outs are in the correct rotation according to the pattern shown on Sheet #1. If these angles are not correct, the exercise will not work.

Conducting The Exercise

■ A notebook or, preferably, a clipboard should be provided. A pencil with an eraser is also strongly recommended.

■ Explain to students that the cut-outs represent outcrops and, as such, are visible glimpses of the Earth's crust. In other words, pretend that most of the court is actually covered by soil and the cut-outs are bedrock poking up through the soil creating outcrops.

■ Hand out Sheet #2 to students. (the blank outcrop template sheet) This sheet shows the position of the outcrops relative to each other.

■ Notice the legend and what rock type that each pattern represents.

■ Each cut-out has an index number for reference.

■ Ask students to find the outcrops on the floor that corresponds to the outcrops on their blank outcrop sheet, Sheet #2, using the index numbers. As examples, point to a couple of cut-outs and ask students to find them on their blank sheet and give the correct index number.

■**Task #1** (give students a 15-20 minute time limit) For all the outcrops;

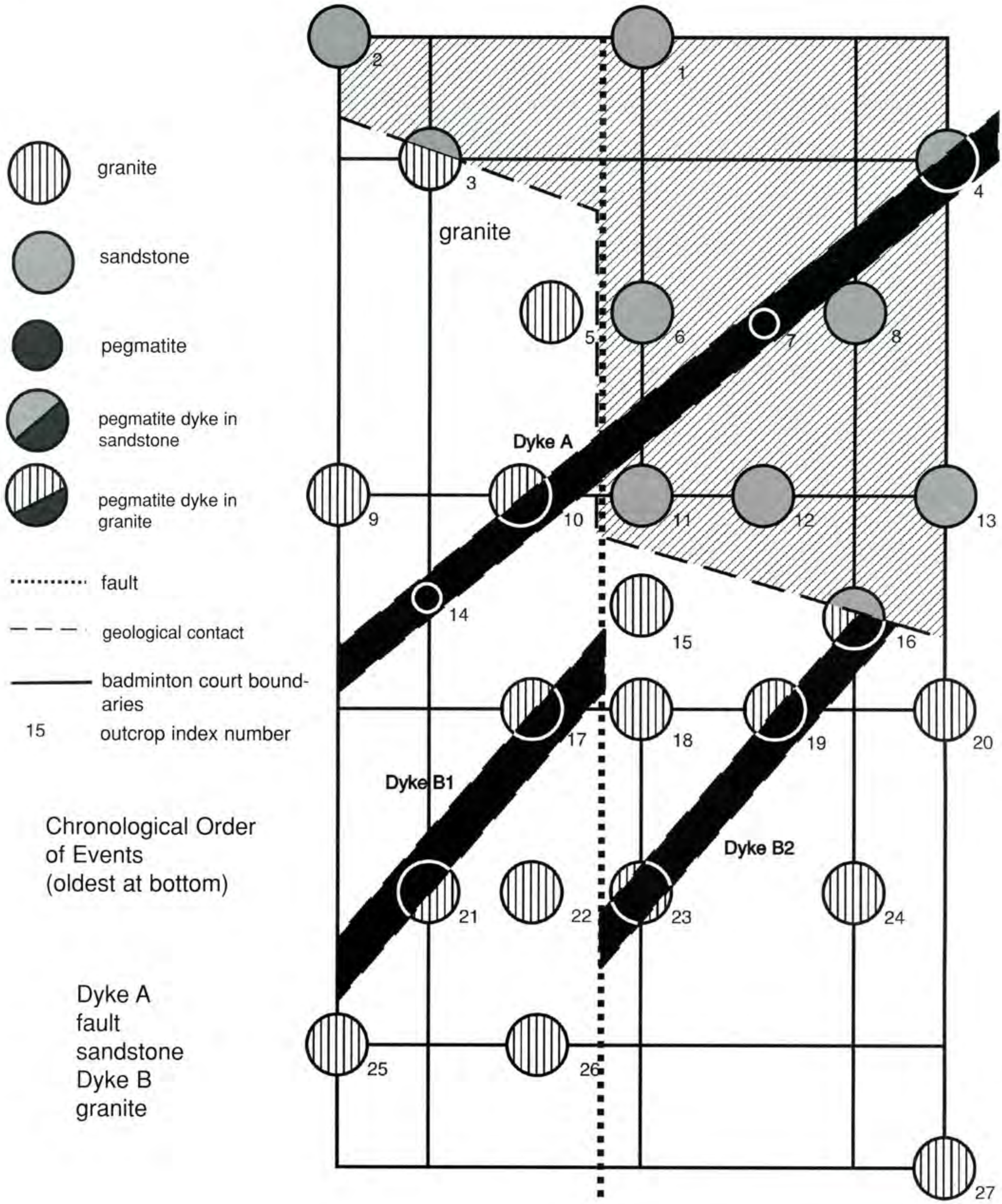
- locate each outcrop on the map

- apply the correct shading according to legend for the rock type indicated by each outcrop

- For outcrops with two or more rock types indicated, draw in the boundaries between the different rock types VERY ACCURATELY including the correct angles as they exist in the cut-outs!!

(teaching note; demonstrate an example of this with at least one multi-rock type outcrop)

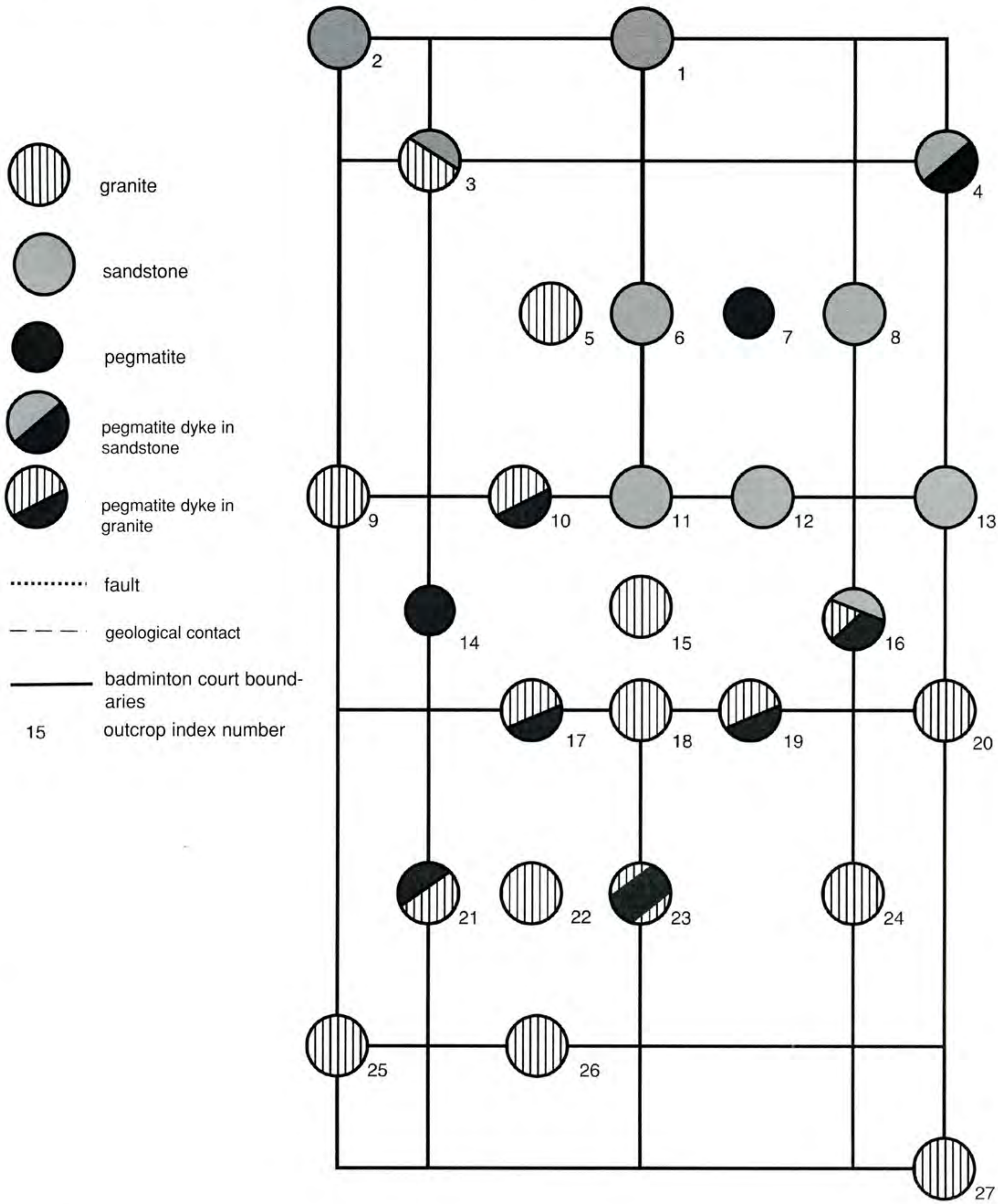
Geological Interpretation



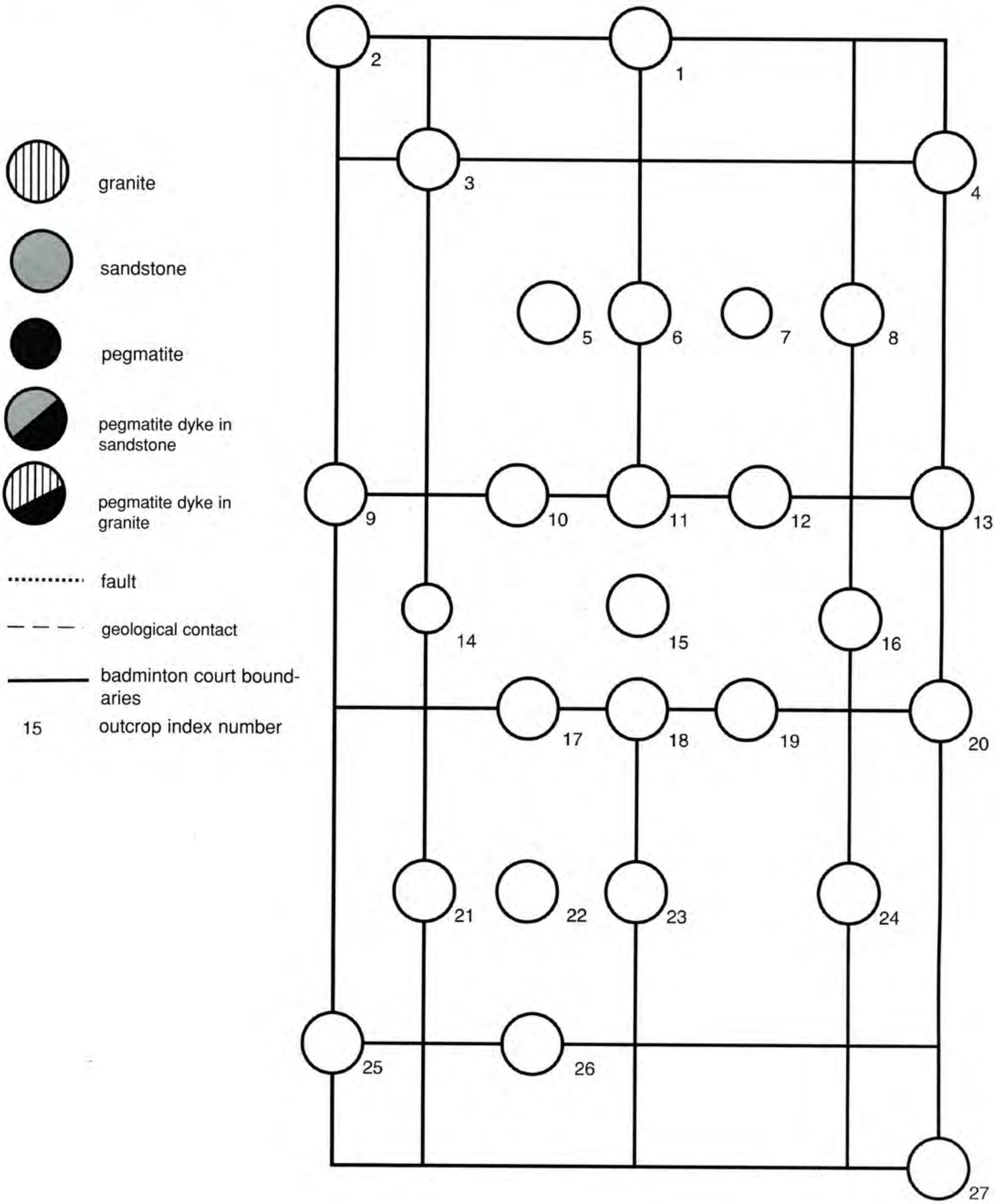
Chronological Order of Events (oldest at bottom)

Dyke A
fault
sandstone
Dyke B
granite

Lay-out Solution



Outcrop Lay-out



○ Do not move any of the outcrops. If any outcrop is accidentally kicked, tell your teacher and the outcrop will be repositioned.

Task #2 Deduce and draw in the geological contacts.

○ Note where geological contacts are actually revealed in the outcrops. These are special places where there needs to be no guessing about where the geological contacts are located. You can see them.

○ There are three types of contacts in this exercise; sandstone against granite (#3, #16), sandstone against pegmatite (#4, #16), and granite against pegmatite (#14, #16, #17, #19, #21, #23)

○ The next step is to connect the geological contacts you can see across areas of the map where the contacts are hidden. This is called "inferring" where the contacts are.

○ Remember that if two outcrops of different rock types are observed, a contact where the two rock types meet must be present somewhere between the two outcrops. Even though this geological contact can't be seen, it has to exist between outcrops of differing rock types.

○ First draw the contact between the granite and the sandstone. Ignore the pegmatite for now. Start with an outcrop that actually reveals the contact between the granite and the sandstone (#3).

■ Scan the map for granite and sandstone outcrops. Place a dot between the granite and the sandstone outcrops.

■ Starting at Outcrop #3, draw a dashed boundary line connecting your in-between dots. There should be a dot between Outcrops #1 and #5, between Outcrops #5 and #6, between Outcrops #10 and #11, between Outcrops #11 and #15.

■ The contact between the granite and the sandstone is also exposed in Outcrop # 16. Connect your new geological contact to this exposed contact.

■ You may safely extend this new geological contact to the edge of the badminton court boundaries beyond Outcrops #3 and #16. The new geological contact should look a bit like a zig-zag line across the page.

■ Again, ignore the pegmatite. If the new granite and sandstone geological contact has been drawn correctly, all the outcrops on one side of the boundary should be granite. All the outcrops on the other side of the boundary should be sandstone.

■ Now, draw in the pegmatite boundaries. Notice in Outcrop #23 that the pegmatite is occurring in narrow, linear structures. These are called dykes. Assume that the dykes are around the same thickness as shown in Outcrop #23.

■ Start with Outcrop #4. Notice that the dyke boundary in the outcrops trends toward Outcrop #7 which is all pegmatite. Continuing along the same trend, notice that Outcrop #10, which is also partly pegmatite, lines up with Outcrops #4 and #7. Again, notice that Outcrop #14 is also along the same trend.

■ All four of the above outcrops can be connected including the visible boundaries in Outcrops #4 and #10, by drawing a narrow band across the page. This indicates a pegmatite dyke cross-cutting the sandstone and the granite.

■ Scan the outcrop layout. Notice that this mapped dyke (Dyke A) does not seem to connect at all with the other pegmatite in Outcrops #17 #19, #21 or #23. There must be more than one dyke.

■Outcrop #21 and #17 show pegmatite boundaries that indicates a common dyke direction. Draw in a narrow dyke structure that connects Outcrops #21 and #17. This dyke has to "dead end" because no pegmatite is present in Outcrop #15. End this new dyke between Outcrop #15 and #17. Call this dyke, "Dyke B1".

■ Outcrops #23, #19 and #16 show other pegmatite boundaries that indicates a common dyke direction. Draw in a narrow dyke structure that connects Outcrops#23, #19 and #16. This dyke has to "dead end" because no pegmatite is present in Outcrop #26. End this new dyke between Outcrop #26 and #23. Call this dyke, "Dyke B2".

■This third dyke shows something else interesting in Outcrop #16. The pegmatite does not cut into the sandstone.

■ All rock type boundaries have now been defined. You are well on your way to creating a geological map. Refer to Solution Sheet #3.

■ Another geological feature can now be inferred from your interpretation of the data. Notice two things;

○ Dyke B1 and "Dyke B2 are parallel. The dead ends of these two dykes in the middle of the map could at one time have lined up and been connected to form one dyke. It appears that one dyke was off-set by what is called faulting. The faulting created Dyke A and Dyke B which were originally the same dyke.

○ Also notice the zig-zag boundary between the granite and the sandstone. This zig-zag boundary indicates that the granite and the sandstone have also been off-set by by faulting. The shifting in the granite and the sandstone is the same distance and direction as the shifting of Dyke B.

○ Draw a line to indicate a fault. Suggest how the fault cuts across the map area to explain the off-set of the granite/sandstone boundary and Dyke B.

Task #3 Interpret the relative order of geological events. Put the sandstone, granite, the fault, Dyke A and Dyke B in order of occurrence.

■ The oldest item or event in the map area will be what is cross-cut by everything else. Remember that the cross-cutting element has to be younger than what is being cross-cut.

■ What is being cross-cut by both dykes and the fault? (the granite) The sandstone is NOT being cross-cut by Dyke B (outcrop #16), so, the sandstone cannot be the oldest. Therefore the granite is the oldest.

■ Next.... Outcrop #16 holds another interesting piece of information. Dyke B2 extends up to the contact between the sandstone and the granite but does not cross into the sandstone. This simple fact makes the age relationships between the sandstone, granite and the Dyke B2 very clear. First of all, between the granite and the pegmatite of Dyke B2, which must be younger? Because the dyke is igneous forming from hot fluids invading a crack or fissure in the granite, the pegmatite (Dyke B2) must be the younger of the two.

■ Dyke B2 is observed to not cross into the sandstone. This shows that the sandstone was emplaced after the dyke was introduced. If the opposite were true the dyke would cross-cut the sandstone as well as the granite. Using these observations, the relative ages of these three rock types is known. The order from oldest to youngest is granite, pegmatite (Dyke B2) and sandstone.

■ The cross-cutting relationship between Dyke A and the sandstone says that the pegmatite of Dyke A is younger than the sandstone. But it is also known that the sandstone is younger than the other pegmatite and the granite. The order from oldest to youngest for all four identified rocks must then be granite, pegmatite (Dyke B2), sandstone, and pegmatite (Dyke A).

■ From the mapping of the entire area, Dyke B1 and Dyke B2 can also be interpreted to have been off-set or faulted. These two dykes were originally the same dyke. The shifting of Dyke B1 and Dyke B2 is mimicked by the sandstone/granite boundary showing the same shift direction and amount of off-set.

■ The fault has off-set the granite, the sandstone and Dyke B, but not Dyke A. Therefore, the fault must be older than Dyke A, but younger than everything else.

■ Therefore, the order of geological events is:

- pegmatite (Dyke A) **Youngest**
- fault
- sandstone
- pegmatite (Dyke B)
- granite **Oldest**

■ By just looking at the positions of the rocks with respect to each other, the relative order of geological events can be figured out. Accurate geological mapping and interpretation can help piece together the Earth's history, even though events happened millions if not billions of years ago.

EDITORIAL

If anyone didn't believe that everyone should have some basic geological knowledge, then the events of late December 2004 should have driven this point home. As Earth scientists we know where most of the major risks caused by plate movements will occur. Some basic education in cause and effect relationships between earthquakes, sea withdrawal and tsunami surges might have saved hundreds if not thousands of lives. The siting of the hotels at Phi Phi on a tombolo connecting a headland to the mainland was asking for a disaster. The waves refracting around the projecting headland concentrated the tsunami surge so that the buildings on the connecting spit were hit from both sides at once. Of the 18 resort hotels at Phi Phi, only three are operational. One could go on, but space is short. This issue covers the tsunami of 2004, a section on the mineral talc, an expose on fossils; a visit to "The Temple of Serapsis" (another part of the world where the sea-floor is unstable) and a geologic mapping exercise, all in your local basketball court! Enjoy, and have a happy and healthy 2005! ***Alan Morgan***

INSIDE THIS ISSUE

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