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VollieNews

NEWSLETTER OF THE POVG - THE PERTH OBSERVATORY VOLUNTEERS' GROUP INC.

'Aliens' found in Siberia!

MOSCOW:
Russian scientists claim to have discovered the wreck of an alien device at the site of an unexplained explosion in Siberia almost hundred years ago.

Interfax news agency said the scientists, who belong to the Tunguska space phenomenon public state fund, said they found the remains of an extra-terrestrial device that allegedly crashed near the Tunguska river in Siberia.

They also claim to have discovered a 50 kg rock which they have sent to the Siberian city of Krasnoyarsk for analysis.

The Tunguska blast, in a desolate part of Siberia, remains one of the 20th century's biggest scientific mysteries.

On June 30, 1908, what is widely believed to be a meteorite exploded a few kilometres above the Tunguska river, in a blast that was felt hundreds of kilometres away and devastated over 2000 square kilometres of Siberian forest.

But the exact nature of the body that exploded and its origin remain a mystery which has spurred countless theories and controversies.

Mike Freeman
(West Australian, 13/8/04)

Astronomy News

BRIGHTEST SUPERNOVA IN A DECADE CAPTURED BY HUBBL

A University of California, Berkeley, astronomer has turned the NASA Hubble Space Telescope on the brightest and nearest supernova of the past decade, capturing a massive stellar explosion blazing with the light of200 million suns.
http://spaceflightnow.com/news/n0409/04supernova/

SPACE STATION RESIDENTS COMPLETE SPACEWALK

Space station commander Gennady Padalka and flight engineer Michael Finckestaged a five-hour 21-minute spacewalk Friday, successfully installing anew coolant system component and three antennas that unmanned European cargo craft will use for future dockings.
http://spaceflightnow.com/station/exp9/040903spacewalk.html

CASSINI CRAFT REVEALS SATURN'S COOL RINGS

The Cassini spacecraft has taken the most detailed temperature measurements to date of Saturn's rings. Data taken by the composite infrared spectrometer instrument on the spacecraft while entering Saturn's orbit show the cool and relatively warm regions of the rings.
http://spaceflightnow.com/cassini/040902coolrings.htm

MARS ROVER'S STUCK ROCK CUTTING TOOL FIXED

NASA's Mars Exploration Rover Opportunity has resumed using its rock abrasion tool after a pebble fell out that had jammed the tool's rotors two weeks ago.
http://spaceflightnow.com/mars/mera/040901status.html

SMALLEST EVER EXTRA-SOLAR PLANET DISCOVERED

European team of astronomers has discovered the lightest known planet orbiting a star other than the sun. The new exoplanet orbits the bright star mu Arae located in the southern constellation of the Altar. It is the second planet discovered around this star and completes a full revolution in 9.5 days.
http://spaceflightnow.com/news/n0408/30planet/

ENVISAT WITNESSES RETURN OF THE SOUTH POLAR OZONE HOLE

The smudges of dark blue on this Envisat-derived ozone forecast trace the start of what has unfortunately become an annual event: the opening of the ozone hole above the South Pole.
http://spaceflightnow.com/news/n0409/04ozonehole/

HELIOS MISHAP REPORT ISSUED BY NASA OFFICIALS

The board that investigated the loss of the remotely operated Helios Prototype aircraft during a test flight last summer released its final report Friday.
http://spaceflightnow.com/news/n0409/03helios/

SCIENTISTS DISCOVER A NEW CLASS OF EXTRASOLAR PLANETS

Astronomers have announced the first discovery of a new class of planets beyond our solar system about 10 to 20 times the size of Earth - far smaller than any previously detected. The planets make up a class of Neptune-sized extrasolar planets.
http://spaceflightnow.com/news/n0408/31planetclass/

Russian Alien Spaceship Claims Raise Eyebrows, Skepticism

An expedition of Russian researchers claims to have found evidence that an alien spaceship had something to do with a huge explosion over Siberia in 1908. Experts in asteroids and comets have long said the massive blast was caused by a space rock.

The new ET claim is "a rather stupid hoax," one scientist said today. And it's one with a rich history. The latest claim was written up by news wires and was making the Internet rounds Thursday morning. According to Agence France Presse, the scientists say they've found "an extraterrestrial device" that explains "one of the 20th Century's biggest scientific mysteries," a catastrophe that flattened some 800 square miles of Siberian forest in a region called Tunguska.

Various other news reports told of a "technical device" and "a large block made with metal." The researchers were said to chip a piece off for laboratory study.

Most scientists think the Siberian devastation was caused by a large meteorite which, instead of hitting the ground, exploded above the surface.

'PLAN TO UNCOVER EVIDENCE'

The Russian research team is called the Tunguska Space Phenomenon foundation and is led by Yuri Labvin. He said in late July that an expedition to the scene would seek evidence that aliens were involved.

"We intend to uncover evidences that will prove the fact that it was not a meteorite that rammed the Earth, but a UFO," Labvin was quoted by the Russian newspaper Pravda on July 29.

"I'm afraid this is a rather stupid hoax," said Benny Peiser, a researcher at Liverpool John Moores University in the UK. "The Russian team stupidly stated long before they went to Siberia that the main intention of their expedition was to find the remnants of an 'alien spaceship!' And bingo! A week later, that's what they claim to have found."

Peiser studies catastrophic events and related scientific processes and media reports. He runs an electronic newsletter, CCNet, which is among the most comprehensive running catalogues on the subject.

"It's a rather sad comment on the current state of the anything-goes attitudes among some 'science' correspondents that such blatant rubbish is being reported — without the slightest hint of skepticism," Peiser told SPACE.com.

LONGSTANDING MYSTERY

Asteroid experts don't have all the answers for what happened at Tunguska. There were few witnesses in the remote region and the explosion left no crater.

The Tunguska event in 1908 flattened 800 square miles of Siberian forest — and the object didn't even reach the ground. Astronomers say similar events will occur in the future, and one over a populated area would be devastating.

But the available evidence, along with modern computer modelling and general knowledge of space rocks, leaves little doubt in most scientific minds as to what happened.

Author Roy Gallant spent 10 years investigating the scene of the event for his book, *"Meteorite Hunter: The Search for Siberian Meteorite Craters"* (McGraw-Hill, 2002).

In an interview with SPACE.com when the book was published, Gallant said scientists are gathering "accumulating evidence tending to support the notion that the exploding object was a comet nucleus. This is the collective opinion of most Russian investigators; although some say they cannot confidently rule out a stony asteroid."

Peiser said there is a "general consensus" among experts worldwide that the culprit was an exploding comet or asteroid.

"Not surprisingly, the blast did not leave any remains of the object intact," Peiser said. "However, researchers claim to have found evidence of increased levels of cosmic dust particles in Greenland ice cores which are dated to 1908 and which they link to the Tunguska event of the same year."

LONGSTANDING SPECULATION

Speculation about aliens and Tunguska go way back. And there is a reason: No other visitor from space — natural or otherwise — has had such a well-documented impact on daily life in modern history. The explosion on June 30, 1908 was equivalent to 20 million tons of TNT.

"Witnesses twenty to forty miles from the impact point experienced a sudden thermal blast that could be felt through several layers of clothing," writes Jim Oberg in *"UFOs & Outer Space Mysteries"* (Donning Press, 1984). The blast was recorded as an earthquake at several weather stations in Siberia."

In Europe, it didn't get dark that night. People said they could read the newspaper by the light of the mysterious blast, Oberg reports. Telescope operators in America noticed degraded sky conditions for months.

No crater was found, and wild speculation ensued.

ENTER SCI-FI

Struck by the similarity of Tunguska and Hiroshima decades later, a science fiction writer named Kazantsev wrote a story in which the Tunguska blast was the exploding nuclear power plant of a spaceship from Mars, according to Oberg.

A few Russian scientists took up the cause and claimed to find various bits of evidence — never substantiated — for a civilised alien explanation. Oberg wrote in 1984 that even then, as evidence built for a natural cause, a handful of "spaceship buffs seem to have grown more desperate, but no less effective, in corralling the public's attention." He said annually some unsuspecting journalist would stumble on the claims and write about them, setting off a fresh round of public speculation.

On that front, little has changed since 1984.

Astronomer Philip Plait, author of the myth-debunking book *Bad Astronomy* (Wiley & Sons, 2002), agrees with Peiser that the Russian researchers intention for finding ET-evidence hurts their case.

"They are not undertaking a scientific expedition, that is, an unbiased investigation to see what happened," Plait said Thursday via e-mail. "They are going to try to prove their preconceived ideas. That's not science, that's religion. And it almost certainly means that they are more willing to ignore or play down any evidence that it was a comet or rock impact, while playing up anything they find consistent with their hypothesis."

PROVE IT

Whatever anyone believes, Plait points out that proof is what's important.

"I am not saying they didn't find an alien ship. I am saying that it's a) unlikely in the extreme, and b) they are predisposed to make such claims, which means we need to be very skeptical, even more so than usual in such cases. If they provide sufficient evidence, then scientists are obligated to investigate, of course. But given everything I've read, their evidence to even consider a non-natural cause is pretty weak."

Plait has even thought about what evidence might be necessary. A chunk of debris would help, but not just any sort of material.

"It would need a weird ratio of isotopes, for examples, or clear evidence of long duration space travel," he said. "Even then they must be careful; manmade space debris rains down on Earth all the time."

Plait, a naturally skeptical person, is willing to wait and see.

"Let's see what these guys bring back," he said. "In the end, it's not what they can claim but what they can support with factual evidence that counts. The burden of proof is clearly — and heavily— on them."Caption: The Tunguska event in 1908 flattened 800 square miles of Siberian forest — and the object didn't even reach the ground. Astronomers say similar events will occur in the future, and one over a populated area would be devastating.

By Robert Roy Britt Senior Science Writer
http://www.space.com/scienceastronomy/tunguska_event_040812.html

POVG Minutes

Perth Observatory Volunteer Group Inc.
Minutes of Meeting August 9th 2004

Present.
L.Martin. M.Freeman. J.Morris. D.Emrich.
J.Biggs. E.Walker. R.Boelen
M.Zengerer. G.Lowe. M.Haslam. D.Alderton.
F.Bilki. G.Coletti. L.Robinson. R.Tanello.
T.Beston. B.Harris.

Apologies.
J. Alcroft

Confirmation of Minutes. Agreed that they were a true and correct record
Moved B.Harris. Seconded F.Bilki

Business Arising from the Minutes.

M Freeman reported that our application for a Commonwealth Grant to assist in the purchase of new jackets and hats had not been successful, ideas for alternative forms of funding would be appreciated.

Treasurers Report.

The Bank balance had increased temporarily due to an influx of funds from deposits paid by members going on the trip to the Shoemaker Crater. Payment to "Travelabout " was due at the end of August and the Treasurer would present a current amended balance at the next meeting.

B.Harris stated that the travel company had expressed interest in bringing tour groups to the Observatory for Night Tours, but they might be at short notice, J.Biggs that they would be welcome providing we could arrange Volunteers at short notice.

Chairman's Report.

M.Freeman stated that only one seat remained unsold for the Shoemaker Trip and was hopeful that it would be taken by the end of the month
Final payment was required by August 31st. The Tour Company had asked to be advised if anyone going on the trip had special dietary requirements.

General Business.

J.Biggs and the staff of the Observatory were thanked by M.Freeman for the end of season get together, it had been most enjoyable . G.Lowe was thanked for his efforts in arranging the evening.

In answer to a question from J.Biggs members were unanimous in their support of the concept of inviting partners to attend future function

J.Biggs gave details of the Observatory stand at the opening of the new Convention Centre, The Centre would be open free to the public for several days, Volunteers would be needed to man the stand, would anyone able to assist contact P.Birch for dates and times

M.Freeman reported that a Radio free zone was to be established in the Murchison area, this was in preparation for the building of Radio Telescopes .

J.Morris stated that his efforts to establish the identity of the author of the handwriting on the Flamsteed Star Atlas in the Display room had raised some interesting facts ,and he had agreed to give a talk on the subject at the next meeting in September.

There being no further General Business the meeting closed at 7.45pm

Next Meeting September 6th.

FREE LECTURE

There's a very topical lecture on the eve of the much vaunted trip to the Shoemaker Impact Structure, which will also be visiting the Yarrabubba Structure. Many thanks to Frank Bilki (POVG) for bringing it to Consulting geologist John Bunting is giving a talk at the Geological Society of Australia entitled "The Yarrabubba Structure, Western Australia - clues to identifying impact events in deeply eroded ancient cratons"

John will discuss how the structure has no obvious surface expression, but was discovered purely by recognition of impact related changes within a single microscopic thin section back in 1979. It was not confirmed to be of impact origin until further work in 2003.

Where: UWA, Geography Lecture Theatre 1
Ground floor, Geology-Geography Building
(enter via Fairway Entrance No. 1)
free parking after 5 PM
When: 5:30 PM, Tuesday 7 September
Cheers. Bevan.

PHASES OF THE MOON FOR 2004

New Moon	First Quarter	Full Moon	Last Quarter
		Jan 7 23:40	Jan 15 12:46
Jan 22 05:05	Jan 29 14:03	Feb 6 16:47	Feb 13 21:40
Feb 20 17:18	Feb 28 11:24	Mar 7 07:14	Mar 14 05:01
Mar 21 06:41	Mar 29 07:48	**Apr 5 19:03**	**Apr 12 11:46**
Apr 19 21:21	**Apr 28 01:32**	May 5 04:33	May 11 19:04
May 19 12:52	May 27 15:57	Jun 3 12:19	Jun 10 04:02
Jun 18 04:27	Jun 26 03:08		
	25 11:37	Aug 1 02:05	Aug 8 06:01
Aug 16 09:24	Aug 23 18:12	Aug 30 10:22	Sep 6 23:10
Sep 14 22:29	Sep 21 23:53	Sep 28 21:09	Oct 6 18:12
Oct 14 10:48	Oct 21 05:59	Oct 28 11:07	Nov 5 13:53
Nov 12 22:27	Nov 19 13:50	Nov 27 04:07	Dec 5 08:53
Dec 12 09:29	Dec 19 00:40	Dec 26 23:06	

http://www.wa.gov.au/perthobs/hpc5mn03.htm

Perth Observatory Volunteers' Group

2004/05 Volunteer Training & Meeting nights

	PERTH OBSERVATORY STAFF
Dr Jamie Biggs	Director and Govt Astronomer
Peter Birch	Astronomer
Ralph Martin	Astronomer
Dr Andrew Williams	Astronomer
Rick Tonello	Astronomer Assistant
Greg Lowe	Astronomer Assistant
Janet Bell	Administration Officer
Di Johns	Clerical Officer
Arie Verveer	Technical manager
John Pearce	Mechanical technician
Marc Appelhof	Maintenance Person/Cleaner

	POVG VOLUNTEERS
Mike Freeman	Chairperson
Elaine Walker	Vice Chairperson
John Morris	Secretary
Bevan Harris	Treasurer and newsgroup moderator (contact: ngc2070@bigpond.com)
Jeff Alcroft	Editor (contact: callides@iinet.net.au) or through newsgroup

Observatory's Volunteers' Active Member List

Jeff Alcroft	Eve Cowlishaw	Bert Hollebon	Lloyd Robinson
Dick Alderson	Giuseppe Coletti	Karen Kotze	Sascha Schediwy
Jeanne Bell	David Emrich	Vic Levis	Val Semmler
Trevor Beardsmore	Keith Ford	Rob Loney	Patricia Turner
Lyall Bell	Mike Freeman	Andrew MacNaughtan	Elaine Walker
Frank Bilki	Lynda Frewer	Len Martin	Sandra Walker
Tony Beston	Bevan Harris	Jacquie Milner	Matthew Zengerer
Ric Boelen	Mark Haslam	John Morris	

Training is important for our volunteers, they enjoy it and we need to support these staff members in return for the assistance they render.

Generally, these training nights are scheduled for 7pm the Monday after the week of Last Quarter.

This list (or a part thereof) is also displayed on the volunteer notice board. Your cooperation is appreciated. Jamie Biggs. Govt Astronomer.

2004

11 Oct 8 Nov 6 Dec

2005

10 Jan 7 Feb 14 Mar
4 Apr 9 May 30 May
4 Jul 1 Aug

Have you joined the POVG Newsgroup yet?

If you've got any news, information or pics post them on the newsgroup.
To join simply send your email address to Bevan Harris at:
ngc2070@bigpond.com

To unsubscribe send an email to:
perthobsvollies-unsubscribe@yahoogroups.com.au
To modify your subscription, visit the group website at:
http//au.groups.yahoo.com/mygroups

PERTH OBSERVATORY
337 Walnut Road, Bickley WA 6076

POVG
Perth Observatory Volunteers Group

PERTH OBSERVATORY VOLUNTEER GROUP

SHOEMAKER IMPACT STRUCTURE AND THREE OTHER IMPACT FEATURES OF WESTERN AUSTRALIA

A FIELD GUIDE

BY F. P. BILKI AND M. J. FREEMAN

PERTH OBSERVATORY VOLUNTEER GROUP

SHOEMAKER IMPACT STRUCTURE
AND
THREE OTHER IMPACT FEATURES
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Cover: Landsat Enhanced Thematic Mapper satellite image of the Shoemaker Impact Structure, 100 km NE of Wiluna, WA, acquired 5 May 2000. False colour image enhancement by assigning red pixels to infrared light (Band 7), green pixels to near infrared light (Band 4), and blue pixels to visible blue light (Band 1). The image has been further enhanced by merging the colour information with a high resolution B&W image of the same area to produce an apparent pixel resolution of 14.25 m. Blue and cyan areas signify ephemeral salt lakes, green signifies vegetation, pale brown signifies bare soil, and the various shades of dark reddish brown signify exposed rock. North is up; horizontal field of view is about 50 km.
Data courtesy of Global Land Cover Facility, University of Maryland.

Compiled by Perth Observatory Volunteer Group Inc.
in collaboration with the Perth Observatory

PERTH OBSERVATORY

Walnut Road
Bickley WA 6076

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SHOEMAKER IMPACT STRUCTURE
AND
THREE OTHER IMPACT FEATURES OF WESTERN AUSTRALIA

A field guide

by

F. P. Bilki and M. J. Freeman

Introduction

This field guide has been prepared for participants in the field excursion *Shoemaker Impact Structure and three other impact features of Western Australia*, sponsored by the Perth Observatory Volunteer Group inc., in collaboration with the Perth Observatory, in September 2004. The guide outlines the regional geological setting of Western Australia and the geology of the four relevant impact features, the Dalgaranga Meteorite Crater and the Shoemaker, Yarrabubba and Yallalie Impact Structures. Background information on the impact process, Western Australia's mining heritage, and the astronomical objects visible during the excursion is also provided.

The Perth Observatory Volunteer Group inc. (POVG) is a non-profit-making, incorporated body of people who provide voluntary support to the Perth Observatory. The Perth Observatory is the Western Australian Government astronomical observatory, established in 1896 to provide essential services to the West Australian community, and is a component of the Department of Conservation and Land Management. The Volunteers provide assistance in the Public Viewing program of education and community support and in collating and cataloguing the extensive library of astronomical photographs.

The field excursion is a self-supporting, though non-profit-making, trip, arranged and organised by members of the POVG.

This field guide is compiled for the benefit of trip attendees, and it is assumed that they will have little knowledge of the geological concepts of impacts or of the geology of the country traversed. We have attempted to minimise the use of geological terms, but we believe we need to use many, and therefore a comprehensive Glossary is included. Terms defined in the glossary are italicised where first used.

Geological times are incomprehensively long periods. Appendix 2 contains a list of geological periods and major events, converted to a "geological year" to help better understand and relate geological times.

Protection of Geological Value

The sites described in this guide provide an invaluable record of Australia's geological history. Damage to them is unacceptable because they will be needed for research and interest well into the future. Please minimise your impact on these sites by:

- Not taking or damaging any *shatter cones* or parts of cones;
- Not using a geological hammer indiscriminately;
- Not walking on or driving over any parts that may be affected by your passage; and

- Noting any apparent major damage and reporting it to the Director of the Geological Survey of Western Australia (100 Plain St, East Perth, Ph: 9222 3333).

Please note that all *meteorites* are the property of the State and must not be removed.

Regional geology of south-western Western Australia

Introduction

The parts of Western Australia the trip passes through consist of three main geological units[1]: the Yilgarn *Craton*, the Earaheedy Basin and the Perth Basin. In addition, the Moora Group underlies a minor part of the route on the edge of the Yilgarn Craton. Overlying these rocks is what is referred to as the *regolith*, which consists of the products of *weathering* of the rocks, either still overlying the parent rocks (such as in situ soils) or transported, such as sand dunes or river alluvium.

Yilgarn Craton

The Yilgarn Craton consists of *granite*, *granitic gneiss* and linear granite-*greenstone* belts trending roughly north-south. The rocks are of *Archaean* age, ranging from 3850 *Ma* (million years) to 2500 Ma. However in places they contain rare zircon grains up to 4410 Ma in the Jack Hills (Wilde *et al*, 2001) or 4350 Ma in the Southern Cross region (Wyche *et al*, 2004), which are the oldest *terrestrial* material known on earth (although meteorites contain older minerals). The Craton covers approximately 400 000 km^2, extending some 1000 km north from the Stirling Ranges and over 800 km east from the Darling Scarp.

Granites are the most common rock and comprise over half of the Craton. They originated as large volumes of molten rock in the lower part of the crust (at depths ranging from 20 km to over 50 km) that migrated upwards into cooler parts of the crust where they froze into the granite *plutons* and plugs. They are now exposed at the surface after *erosion* of the rocks that were overlying the cooling masses.

Granite gneiss or granitic gneiss has the appearance of granite but with a layered structure and appearance. They mostly originated as granite bodies that were later subjected to high temperatures and at high pressure, which resulted in the earlier-formed mineral grains being reconstituted (termed recrystallised). The minerals formed into layers in response to the stresses at the time of the recrystallisation. *Gneiss* is most common in the southwest and northwest parts of the Craton.

Figure 1: Major geological regions of south-west WA and excursion route

The greenstone belts are metamorphosed sedimentary and volcanic rocks that have been severely *faulted* and folded by later earth-movements. They include sediments such as conglomerate, sandstone, shale, chert and banded iron formation. The rocks derived from volcanoes include *basalt*, *rhyolite*, *andesite* and *komatiite*, and include not only the lavas but also various other forms, such as pyroclas-

[1] Geologists usually group rocks into 'units' according to their age, the character of the rocks, and their correlation with similar rocks in other localities. Each rock unit is then named after a local geographic feature, for example *Yarrabubba Granite*. Unfortunately for non-geologists, the name frequently provides no clues about the rock types actually contained within the unit, a situation that typically arises when the unit contains an assemblage of different rock types. Additionally, different names imply different areas of coverage, for example the Eraheedy *Group* covers a greater area than, and also contains, the Chiall *Formation*, which in turn covers a greater area than (and contains) the Karri Karri *Member*.

tics (derived from a gas-borne cloud emitted explosively from the volcano) and a wide range of other rocks. After deposition, these interbedded sediments and volcanics were severely affected by earth-crust movements, faulted, folded and buried to great depth where the original minerals were reconstituted (metamorphosed) to form the present rocks. Most of them were tipped on edge to form the elongate belts of greenstones. Geologists refer to the amount of change as the metamorphic grade. The conditions that produced the metamorphism range from temperatures of 100° C to about 800° C and at pressures equivalent to depths of from near-surface to some 15 km to 20 km (or much greater in some instances).

Most of the Yilgarn Craton's greenstone belts host gold deposits with the Golden Mile at Kalgoorlie being the largest, having produced some 2140 t of gold since its discovery in 1893. Unusual volcanic rocks (geologically termed komatiites) host major nickel sulphide deposits (e.g. Kambalda, Mount Keith) that supply some 20% of the world's nickel metal. A different type of volcanic rock occurs at Golden Grove, about 50 km northwest of Mt Singleton, which contains large deposits of lead-zinc-silver-copper metals. These volcanics are quite different from the nickel-bearing rocks, and geologically are referred to as being *acid*. The main difference is that these rocks have a higher content of *quartz* or silica.

The Yilgarn Craton is bounded to the west by the Darling Fault, a long-lived structure that extends for at least 1000 km from the south coast to east of Shark Bay (Figure 1). To the north the Yilgarn Craton merges into a zone of younger sediments and *metamorphic rocks* referred to as the Gascoyne Complex, to the south into the Albany-Fraser *Orogen* and in the east it is covered with sedimentary rocks. Both of the Orogens represent plate-plate collision zones, where drifting continental plates collided and became joined.

Earaheedy Basin

Earaheedy Basin is a sequence of shale, siltstone, sandstone, with some limestone and ironstone beds. It is up to 5000 m thick. It overlaps the northern edge of the Yilgarn Craton because that area became submerged and the sediments were deposited unconformably on the old land-surface. The timing of this flooding of the sea and deposition of the sediments is not known. It occurred after 2200 Ma and possibly after 1830 Ma, the ages of older sediments below the Earaheedy Basin, and the sedimentation was completed prior to 1210 Ma, the age of sediments that overlie the Basin. This formation constituted the target rocks for the Shoemaker impacting body.

Perth Basin

The Perth Basin comprises a sequence of sedimentary rocks up to 15 km thick that accumulated between Devonian (about 350 Ma) and late Cretaceous (65 Ma) times. They were deposited in a north-south-oriented gulf bounded to the east by the Darling Fault, to the west by the precursor to India, and to the south by the ancestral Antarctica, with the open ocean to the north, termed the Tethyan Ocean.

The Perth Basin sediments are dominated by sandstone with less-common siltstones, widespread, but relatively thin coal, and rare sediments derived from glacial action. Latest research based on dating zircon grains in the sediments implies the Perth Basin sediments were derived from the Albany-Fraser Orogen or the Leeuwin Complex (which occurs between Cape Naturaliste and Cape Leeuwin) rather than from the Archaean rocks of the Yilgarn Craton (Sircombe & Freeman, 1999; Cawood & Nemchin, 2000). The importance of these findings is that it shows that the surface of the Yilgarn Craton has not been eroded much during the past 250 Ma, and this, in turn, implies that there could still be a number of old, large impact structures yet to be found.

Regolith

Most of Western Australia has been a very stable part of the Earth's crust for very long periods. Therefore, even though Australia is renowned as an old continent, this western part has been the epitome of age and geological stability, and has been without mountain ranges for a very long time. This has resulted in long periods of weathering of the near-surface rocks, and soils that are very old and of limited fertility. Recent dating of minerals and interpretations of regional geology suggests that the present surface of the Yilgarn Craton may date back to perhaps Permian times (250 Ma).

Through this long period of exposure, there has been intense weathering and formation of lateritic profiles. These profiles are up to 100 m thick, and formed during periods partly experiencing distinctive climates. Lateritic profiles are distinctively zoned consisting of:

- An uppermost layer of iron-rich (and therefore rusty-looking) caprock that is strong, resists further weathering and erosion and forms a hard capping up to about 4 m thick;
- An intermediate clay layer, up to 10 m thick, that commonly contains parts that are "mottled", with patches of iron-rich clayey material in a *matrix* of bleached clayey material; and
- A lowermost layer that grades into the bedrock and may still retain some of the appearance of bedrock

The laterite profile is economically important in the Darling Range where the caprock constitutes the bauxite ore that gives the World some 20% of its aluminium, and in the goldfields it commonly contains gold or nickel.

Laterite profiles are developed over all rock-types. They characteristically form the breakaways of the outback, where the caprock generates low cliffs on tops of low rises.

Soils and alluvium along watercourses also are included in the term regolith. These materials have very diverse forms and natures, and in general conceal the bedrock. They are, however, very important for life, because they are the material in which humans grow their crops.

Impacts and impact structures

Introduction

Our Solar System probably formed about 4560 Ma ago from the leftovers of an ancient *supernova* (an exploding star). Over time, grains of this material, consisting of hydrogen and helium gas, dust, and heavier chemical elements like iron and carbon, gradually consolidated into solid clumps under the forces of mutual gravitation. Slowly, these clumps grew into *proto-planets*, which eventually became the planets we see today.

As these young planets swept through the debris left over from their own formation, they were subjected to an intense period of on-going bombardment. On the moon, the heavily cratered highlands (light-coloured areas) still carry the scars of this heavy bombardment period, which lasted from 4500 Ma to around 3800 Ma (French, 1998). Since 3800 Ma, the greatly reduced bombardment rate has been almost constant. It was recognised as recently as 1997 (Herres & Hartmann, 2004) that our own Moon probably formed as the result of a catastrophic impact between the proto-Earth and a Mars-sized object (about half the size of the present-day Earth) at around 4500 Ma. The Earth is thought to have swallowed most of this impacting body, with the resulting expelled debris coalescing to become the Moon.

Table 1: Western Australian Impact Structures (From Whitehead, 2004, except where noted)

Name	Age (Ma)	Diameter (km)
Dalgaranga[1]	< 0.003	0.024
Veevers[1]	< 0.004	0.08
Wolfe Creek	< 0.3	0.875
Goat Paddock	< 50	5.1
Connolly Basin	< 60	9
Yallalie	100 ± 30	12
Piccaninny	< 360	7
Woodleigh	364 ± 8	40
Glikson[2]	< 570	18
Spider[3]	> 700	13
Shoemaker[4] (formerly Teague Ring)	1300 – 568	30
Yarrabubba	~ 2000	30

[1] Bevan (1996). [2] Macdonald & Mitchell (2004). [3] Glikson (1996). [4] Pirajno (2002)

Planet Earth would have undergone a similar bombardment and cratering rate as the Moon. However, Earth's unique geological and environmental conditions have conspired to erase or obscure evidence of all but the younger impact features:

- *Plate tectonics* have overturned most of the Earth's crust;
- Weathering and erosion have smoothed out the hills and mountains and in-filled valleys, and

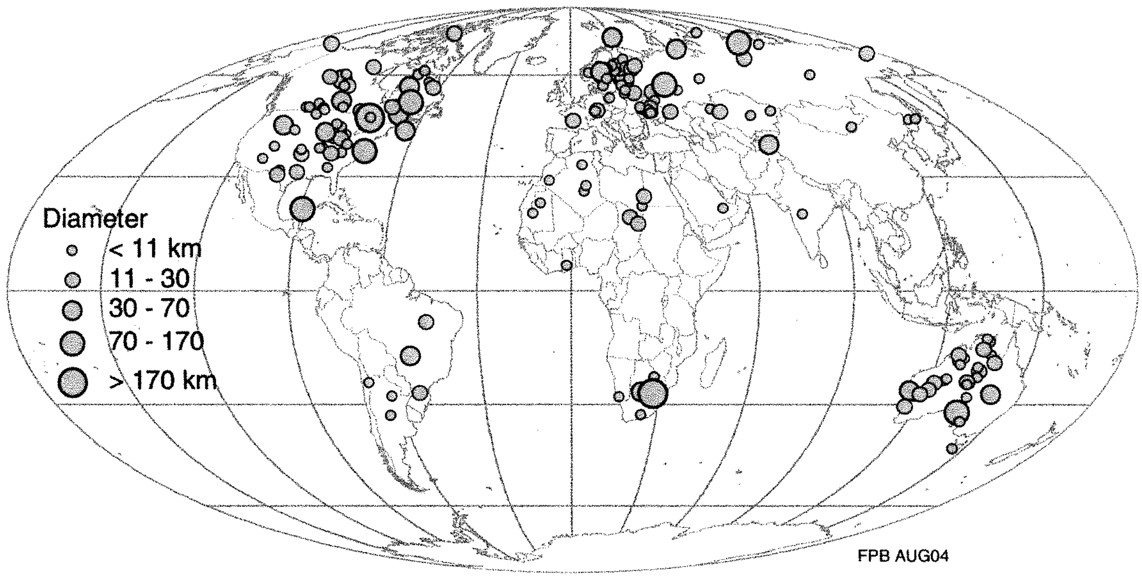

Figure 2: World impact structures (From Whitehead, 2004)

- Oceans and seas obscure three-quarters of the planet's total surface area.

Because the Earth is geologically active, there are only around 175 recognised craters (Whitehead, 2004; Figure 2). In comparison, many thousands of craters have been observed on the Moon, which is geologically dead. Around 28 craters are found in Australia (Figure 3), and new evidence of meteoritic impacts is discovered every year as a result of ongoing research.

The terrestrial impact record is well represented in Western Australia, with three relatively young (and therefore well-formed) meteorite craters and nine old, deeply eroded impact structures being located within the state (Table 1, from Whitehead, 2004).

Asteroids and comets

The Earth is accompanied in space by thousands, if not millions, of kilometre-sized objects, some of which could collide with the planet in the future (French, 1998). These objects can be broadly classified into two categories: Asteroids and Comets.

Most asteroids, or minor planets, lie in a belt situated between the orbits of Mars and Jupiter. The largest known asteroid is Ceres, which is less than 1000 km across, and the next biggest, Pallas and Vesta, are about half that size, but they may occur in all sizes down to specks of dust. Although the vast majority of these rocky objects remain safely within their orbit (and consequently away from Earth), collisions with other asteroids, or gravitational *perturbations* caused by Mars or Jupiter, may occasionally nudge them into an earth-crossing orbit.

On the other hand, most comets are found in the *Oort Cloud*, which is situated at a distance of about 60 000 AU (*Astronomical Units*) from the Sun, or the *Kuiper Belt*, just beyond the orbit of Pluto. Comets are often referred to as 'dirty snowballs' because they contain a significant amount of ice in addition to rocky material. Comets may be perturbed by the Solar System's passage through the Milky Way *galaxy*, or by the gravitational effect of a passing star, similarly placing them in a potentially earth-crossing orbit.

Impact events and near misses

Every day the Earth accumulates about 100 tonnes of extraterrestrial material, mainly as particles ranging from microscopic dust to golf-ball sized objects (French, 1998). These objects burn up in the atmosphere and produce visible streaks of light in the night sky, known as *meteors* or "shooting stars". When viewing the sky on a typical moonless night, an observer will notice around five meteors occur per hour, which are referred to as *sporadic meteors*. However, at certain times of the year this number may increase to thousands per hour. These events are known as *meteor showers* or *meteor storms*, and are caused when the Earth passes through the debris trail left by a passing comet. The Leonid meteor shower, which occurs around mid-November and is the product of Comet Temple-Tuttle, is one such example.

Occasionally a larger object will reach the ground, sometimes in newsworthy circumstances. These objects are known as *meteorites*. For example, at about 9 o'clock on Saturday morning, 12 June 2004, a meteorite crashed through the roof of the home of the Archer family in Ellerslie, Auckland. The rock hit their leather couch and bounced back up to the ceiling before rolling under the computer (IGNS, 2004). The following Wednesday, 17 June, a number of people, including air traffic controllers at Sydney Airport, reported a large, very bright meteor. A fortnight later, on Saturday, 26 June, just after 9 PM, a large meteor lit up the sky over New Zealand's South Island. However, meteorite fragments of the latter two reports remain to be found.

Encounters and near misses with larger objects, although less frequent, have also occurred within recent recorded history. For example, the well-known 1908 Tunguska (Siberia) explosion, which flattened about 2000 km^2 of forest, was probably caused by a 30–50 m object exploding in the sky above the Tunguska River, and many people have now seen movie footage of a fireball passing harmlessly above the United States in 1972.

Between 16 and 22 July 1994, astronomers and sky watchers were treated to the multiple nuclei of Comet Shoemaker-Levy 9 striking the surface of Jupiter. The brighter nuclei were estimated to be between one and three kilometres in size and, had the impact occurred on Earth, the resulting dark clouds would have encircled our home planet in less than 90 minutes (Shoemaker, C., 1999). More recently, on Monday, 15 March 2004, scientists of the NASA-funded LINEAR asteroid survey discovered a 30 m object, which subsequently passed within 43 000 km of Earth the following Thursday,

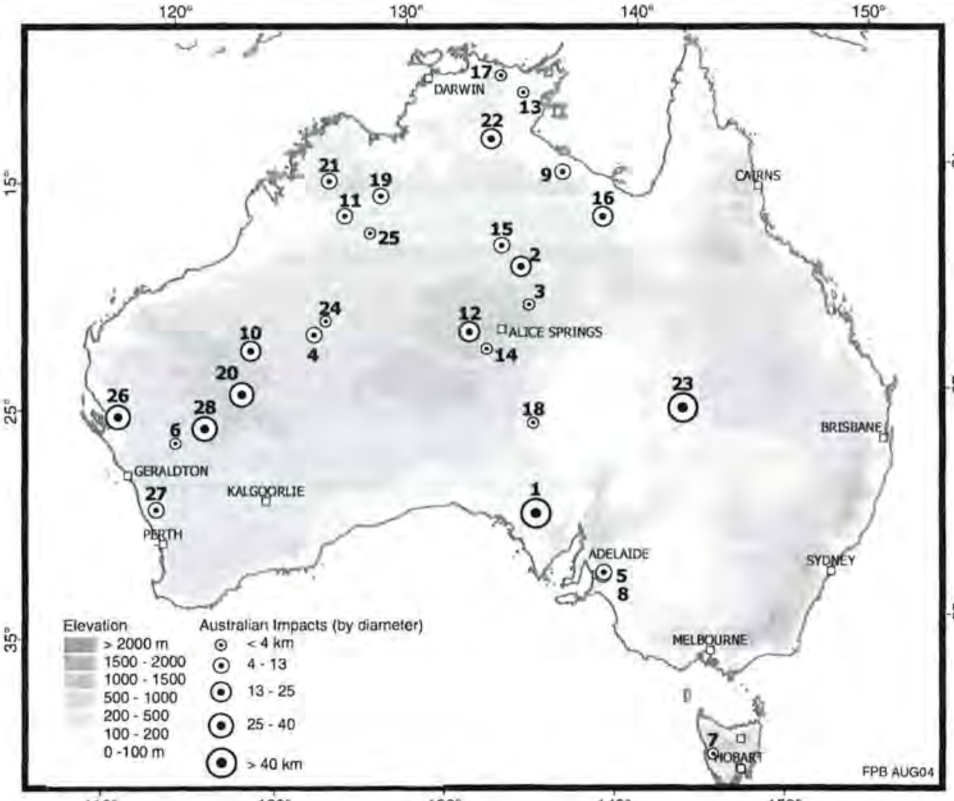

Figure 3: Australian impact structures (from Whitehead, 2004)

1 Acraman	8 Flaxman	15 Kelly West	22 Strangways
2 Amelia Creek	9 Foelsche	16 Lawn Hill	23 Tookoonooka
3 Boxhole	10 Glikson	17 Liverpool	24 Veevers
4 Connolly Basin	11 Goat Paddock	18 Mount Toondina	25 Wolfe Creek
5 Crawford	12 Gosses Bluff	19 Piccaninny	26 Woodleigh
6 Dalgaranga	13 Goyder	20 Shoemaker	27 Yallalie
7 Mount Darwin	14 Henbury	21 Spider	28 Yarrabubba

18 March. The pass-by, which is the closest one recorded to date, occurred above the South Atlantic Ocean, and was so close that the asteroid was visible in binoculars. The Earth's gravitational pull deflected the asteroid's trajectory by 15°, as illustrated in Figure 4.

Impact structures

The ultimate fate of an object entering the Earth's atmosphere depends largely on its size and to a lesser degree on its composition. We have already seen that the smallest objects, golf-ball sized and smaller, burn up harmlessly in the atmosphere and produce no lasting impact structure, if they reach the ground at all. Larger objects, perhaps a few metres or less in size, lose most of their velocity and *kinetic energy* to the atmosphere through *disintegration* and *ablation*. These objects strike the ground at perhaps a few hundred metres per second (about the speed of sound) and excavate a crater slightly larger than the object itself (French, 1998; see Figure 5 for a small-scale example). The craters formed by this process are known as *penetration craters*, of which the Dalgaranga Meteorite Crater is an example.

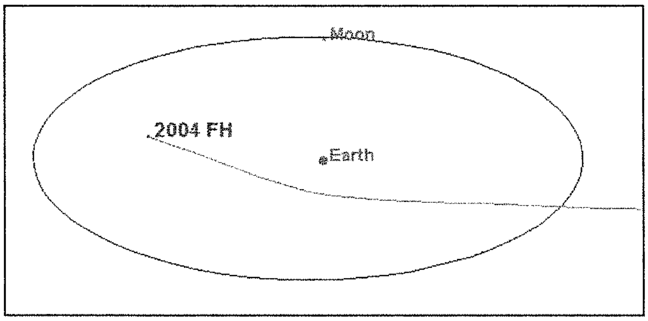

Figure 4: Path of asteroid 2004 FH during its near-Earth flyby (from NASA, 2004)

Objects larger than about 50m in size are largely unaffected by the Earth's atmosphere and strike the ground surface at their original cosmic velocity, which will always exceed 11 km/s and may be up to 75 km/s (O'Byrne, 1997). Such high velocities result in these objects impacting with enormous amounts of kinetic energy. Even a moderately sized object a few kilometres across releases more energy in a few seconds than the entire Earth releases in hundreds or thousands of years through *volcanism*, *earthquakes* and *heat flow* (French, 1998). The composition of the object may also influence the amount of energy released, since comets generally consist of much weaker, less dense material than asteroids, and consequently release less energy on impact. For both asteroids and comets, the released energy produces intense shock wave pressures and temperatures, which permanently alter the affected rocks and excavate large craters many times the size of the original object. These structures are known as *hypervelocity impact craters*. The Shoemaker Impact Structure is a fine, although very old and consequently deeply eroded, example of such a crater.

For both crater types, rain, wind, and erosion will, over time, fill in the crater and level the surrounding crater rim. If the crater formed offshore, the rapid return of seawater blasted away by the shock of impact may fill the depression with marine sediments. On-going deposition of material on the sea floor will eventually cover the whole structure with thick, younger sediments, and our only chance of finding it will be by drilling. Those impacts on land may become deeply eroded, and if geological processes coincide, we may now see rocks that were once at depths of kilometres below the land surface at the time of the impact.

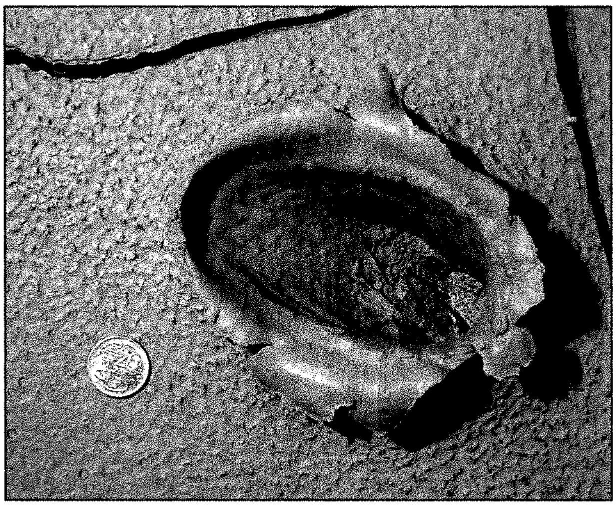

Figure 5: Small penetration crater produced by 'fly rock' from an open pit mine blast landing in thick mud. Note the thin sheet of coherent mud extruded from the target material, forming an overturned 'flap'. Coin is 3 cm diameter

Stages of formation

The formation of a hypervelocity impact crater is an incredibly complex and violent process, which takes only a few minutes for even the largest of craters. Nevertheless, some workers (e.g. French (1998), from which much of this discussion is derived) have shown that the process can be divided into three distinct stages, namely contact/compression, excavation, and modification. Understanding these stages gives us an appreciation of the huge forces and amounts of energy released.

The **contact/compression** stage begins the moment the projectile strikes the ground surface. The projectile stops moving in just a fraction of a second, penetrating into the ground perhaps one or two times its own diameter. (For example, the Chixulub projectile that hit Mexico 63 Ma ago, and probably caused the extinction of the dinosaurs, was about 10 km across and hit at about 20 km/s. Consequently, it buried itself into the Earth in half a second.)

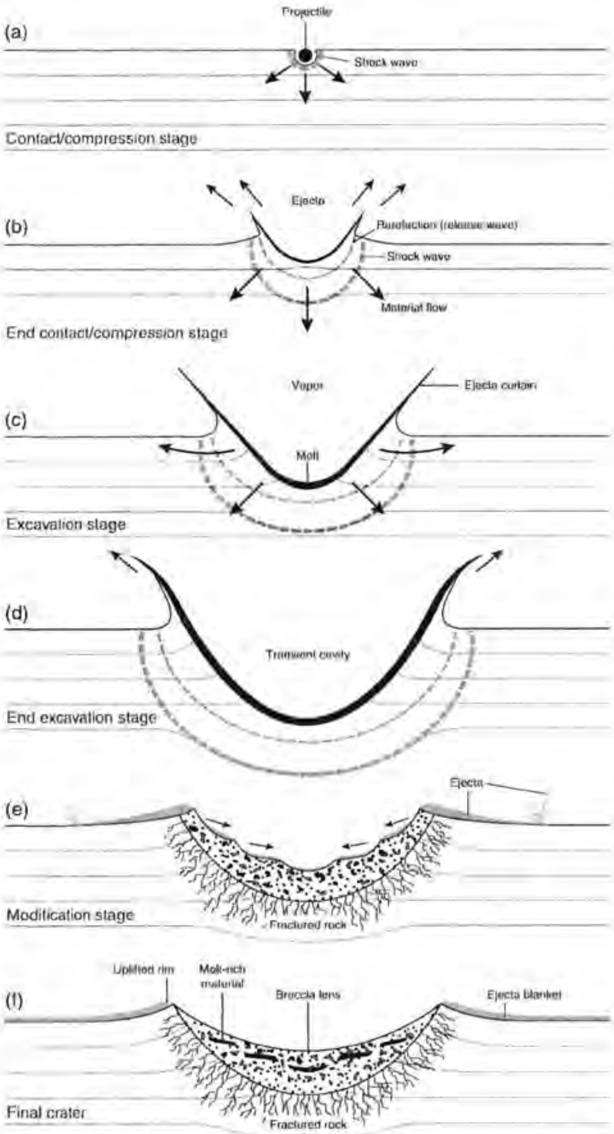

Figure 6: Stages in the formation of a simple impact crater (from French, 1998)

The massive deceleration generates intense shock waves at the point of impact, which travel at velocities exceeding the speed of sound through rock (Figure 6a). Pressures generated by these shock waves are high enough to completely vaporise the projectile along with some of the surrounding target rock at the point of impact, and melt the target rock at greater distances. Lower pressures are generated at yet greater distances from the point of impact, but although these are insufficient to melt the target rock, they are still strong enough to create distinctive shock effects in large volumes of rock.

The contact/compression stage ends when a complex interaction between the shock waves and the ground surface causes a sudden "unloading" of the affected rocks (Figure 6b). It lasts no more than a few seconds for even the largest (~10 km) projectiles; for most impacts, it is over in less than a second.

During the **excavation** stage, the expanding shock waves interact with the ground surface, shattering the target rocks and causing near-surface material to be flung out at high velocities. Deeper rocks are moved downwards and outwards as a coherent mass as shown on Figure 6c. This process creates a bowl shaped depression around 20 – 30 times the diameter of the original projectile.

Eventually, the shock wave pressures drop to those of normal seismic (earthquake) waves, and they are no longer able to displace the target rocks. The distance at which this change occurs defines the radius of the **transient crater**, illustrated on Figure 6d. Beyond this, the rocks are fractured and faulted in the same ways as during normal earthquakes, and similarly, the weakened shock waves are transmitted through the entire earth.

The excavation stage progresses very quickly; some theoretical studies suggest that a 200 km crater is excavated in around 90 seconds. A ~1 km crater such as Western Australia's Wolfe Creek Crater, or Barringer (Meteor) Crater in Arizona (Figure 7), is thought to be excavated in around six seconds.

Even as the excavation stage progresses, ordinary geological forces such as gravity and *rock mechanics* cause the structure to start collapsing. The action of these forces is referred to as the **modification stage**, and in the case of a small (<4 km) crater, debris from the walls and rim immediately slumps back into the crater, filling it to around half its original (transient) depth. This process is illustrated on Figure 6e and f. The 'immediate' part of the modification stage lasts slightly longer than the excavation stage, perhaps up to a few minutes for a large crater. However, it has no clearly defined end, since normal geological forces will continue to act on the structure through time.

The Wolfe Creek crater is an excellent example of this process: despite this crater's young age (about 300 000 years), its depth has already decreased by around 70% owing to the combined effects of erosion of the crater rim and deposition of wind-blown sediments in the crater floor (Grieve & Pilkington, 1996). These workers consider that the crater will cease to exist in crater form in slightly over 100 000 years.

Simple craters

Depending on the size of the transient crater, the resulting impact structure may take one of two main forms. On Earth, this transition occurs at diameters of between two and four kilometres, depending on the strength of the target rocks (French, 1998). (The transition diameter also varies inversely with the gravitational acceleration of the planet, and so varies from one planet to the next within our Solar System). Transient craters smaller than this figure typically form **simple craters**. These structures preserve the basic bowl shape and size of the original transient crater, which is surrounded by a structurally raised rim and an overturned 'flap' of the target rocks, which is in turn overlain by a blanket of the ejected material (Grieve & Pilkington, 1996). Owing to slumping around the crater rim during the modification stage, the crater floor is filled to around half its original depth and the overall diameter of the structure increases by up to 20% (French, 1998). The debris that fills the crater floor typically consists of *brecciated* (broken) and impact-melt rocks. Figure 6 provides a schematic illustration of a simple crater, of which the Wolfe Creek crater is an example.

Complex craters

Terrestrial craters larger than around 4 km diameter are characterised by a centrally uplifted region, a flat floor, and extensive inward collapse around the rim. These structures are known as **complex craters**. The energy released by these larger impacts is enough to overcome the strength of the target rocks, and during the modification stage the interaction between the rocks, gravity, and shock waves causes a complex outward, inward, and upward movement (Figure 8). A simple analogy can be made by dropping a pebble into a pond: the water initially forms a cavity at the point of impact, some water is 'ejected' upwards and outwards, away from the pebble, and a central rebound forms at the point of impact. That many tens (if not hundreds) of cubic kilometres of solid rock behave like water in a pond during a large impact event is testament to the enormous amounts of energy released.

Complex craters are also modified around the edge by collapse of the walls along a series of faults that slope into the transient crater. They may also develop a distinctive series of *anticlines* and *synclines* around the outer parts, such as those developed at the Shoemaker Impact Structure.

Figure 7: Panoramic photograph of Barringer (Meteor) Crater, near Winslow Arizona. Horizontal field of view is about 180°. The crater is about 1.2 km in diameter and 180 m deep; its rim rises between 30 and 60 metres above the surrounding plain. A projectile about 45 m in diameter is thought to have produced the crater about 50 000 years ago. The structures at right are part of the visitor's centre

As the diameter of a complex crater increases, the centrally uplifted region becomes a more complex series of concentric rings and basins. Crater diameters of 4 – 22 km are characterised by a single central-peak uplift. As the diameter increases to around 30 km, the central-peak is replaced with a ring-shaped central-peak-basin, and at diameters of up to around 62 km, this becomes a peak-ring basin structure (French, 1998). (These diameters are based on a small number of terrestrial craters and are therefore very approximate.) The Shoemaker Impact Structure, with a diameter of about 30 km and a central uplift diameter of about 12 km (Pirajno *et al*, 2003), probably represents a peak-ring basin structure (Pirajno, 2002).

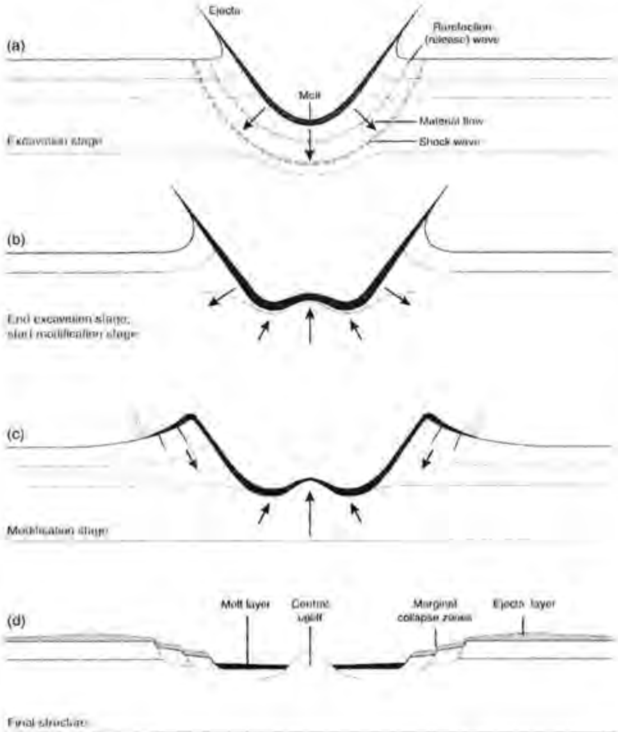

Figure 8: Stages in the formation of a complex crater (from French, 1998)

Identifying an impact crater

Many characteristics of a hypervelocity impact crater can be readily identified by simple observation, whereas others require microscopic equipment and specialist sample-preparation techniques.

Landforms

Impact craters are often characterised by distinct circular features expressed in either the topography (for example, rings of hills or *arcuate* lakes) or geology of the area. The geology of an impact structure may also be significantly different from the surroundings, and there may be an abundance of faulting, fracturing, and brecciation within the crater extents. All of these characteristic features are present at the Shoemaker Impact Structure.

For young structures the original crater, rim and ejecta layer may be preserved, and fragments of the original meteorite may also be present. Older, more deeply eroded structures may only be marked by vague circular patterns of rocks.

Hand-specimen features

The rocks within an impact structure are characterised by intense faulting, fracturing and brecciation. *Dyke*-like and *sill*-like bodies of mixed melt and melt-free rocks are also often present. However, because conventional geological processes may also produce these features, alone they are not diagnostic of impact origin.

The only diagnostic indicator that is visible at hand-specimen scale is the presence of *shatter cones*. These cone-shaped structures are the result of numerous curved, *striated* fractures that typically form partial to complete cones (Figure 9). They mostly occur below the crater floor, generally in the central uplift region of a complex crater, and can range in size from a few millimetres to several metres.

Shatter cone apices typically point inward and upward, and at the time of their formation they point towards the point of impact and origin of the shock wave (Pirajno, 2002). However, they are typically displaced by formation of the central uplift and by later deformation of the sub-crater rocks.

Pseudotachylite is also characteristic of impact structures, however because it may result from other geological processes it is not diagnostic. Pseudotachylite is a partially fused, black to green, dense, very fine grained rock, occurring within irregular dyke-like bodies that may extend for hundreds of metres in large impacts. Numerous large and small rounded to angular inclusions of target rock are usually found within the dykes.

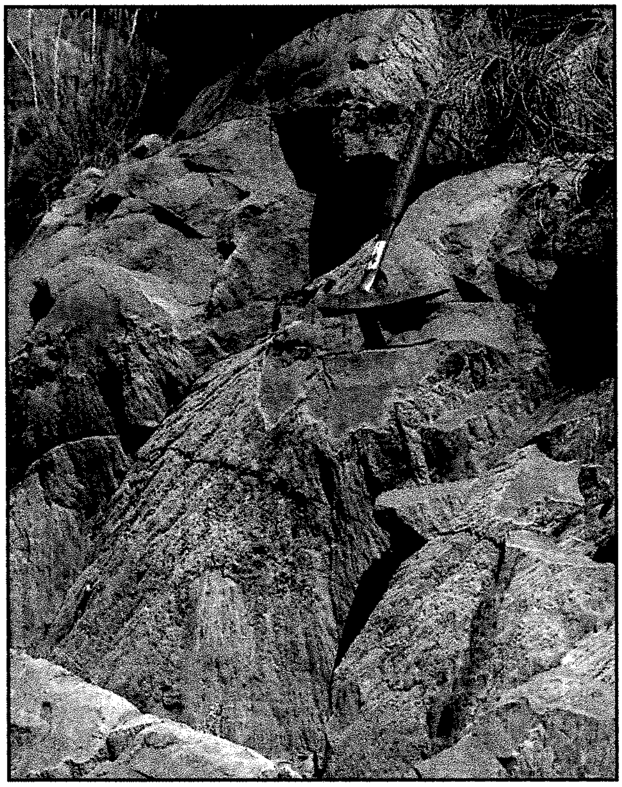

Figure 9: Shatter cone, Gosses Bluff, NT. Large cone-shaped fractures formed in Mereenie Sandstone showing typical horsetail feathering on the surfaces. Hammer is 33 cm long

Under the microscope

The microscopic characteristics of impact craters require specialist equipment to both prepare and analyse the specimen, but they provide the most definitive indication of whether a suspect structure is indeed of impact origin. One of the most widely used characteristics is the presence of **planar deformation features** (PDFs) within quartz and *feldspar* grains. PDFs consist of multiple sets of extremely narrow (<2 μm), closely spaced (2-10 μm) parallel planar regions, which are only produced at the high shock pressures that exist during impact events (French, 1998; Figure 10). These pressures are normally only experienced at depths of at least hundreds of kilometres inside the Earth. The presence of quartz PDFs in the worldwide ejecta layer produced by the Chicxulub impact 65 Ma ago provided some of the most important evidence that a large meteorite impact had occurred at that time (French, 1998).

At higher shock pressures, nearer the point of impact, the shock waves may convert entire crystals to a glassy (*amorphous*) phase, known as **diaplectic glass**. These glasses are characteristic of impact origin because they form without the target rock melting or flowing, and so preserve the original grain fabric of the rock.

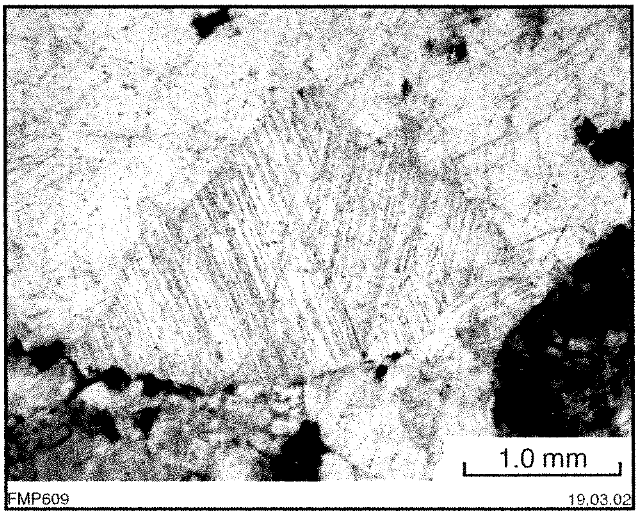

Figure 10: Photograph of Quartz PDFs developed in Teague Granite, as observed through a microscope. Photo courtesy of GSWA

High shock pressures may also transform some minerals to high-pressure variants normally found deep within the Earth's crust. For example, graphite may be converted to **diamond**, and quartz may be converted to **stishovite** and **coesite**. If these minerals are found in near-surface rocks, they are also reliable indicators of impact origin (French, 1998).

By-products of impact events

Meteorites

In some impacts, particularly geologically recent ones that produced penetration craters, the source meteorite may be found. The impacting meteorite is usually vaporised during large impact events. Meteorites are divided into three major categories based on their composition:

- **Irons**: Consist of around 90% iron and 10% nickel. Although irons only contribute about 5% of meteorite falls, their unique appearance and composition mean they are the most commonly recovered meteorites. Irons are characterised by their high density, strong magnetic response, and 'thumbnails' or pits in their outer surface. On exposure to the atmosphere iron meteorites take on a rusty appearance.

- **Stony meteorites**: The most common type of **meteor**, comprising around 90% of material collected by the Earth. However, because they are similar to Earth rocks in composition they are the hardest to identify and are consequently the least recovered **meteorite**. Stones can be further divided into Chondrites, which contain tiny mineral spheres called chrondules, and Achondrites, which do not.
- **Stony-irons**: Contain a mixture of stone and iron.

Many older Australian meteorites, particularly those associated with existing craters, have been extensively corroded. Iron within these meteorites has weathered to balls of 'iron shale', which are nodules of iron oxide (rust) that represent fragments of the original meteorite (Bevan, 1996). A notable exception to this is the Dalgaranga crater, from which some fresh material was recovered (Bevan, 1996). Furthermore, very young meteorites, particularly those that are seen to fall and are recovered soon afterwards, have not been subjected to the weathering process and should remain relatively fresh.

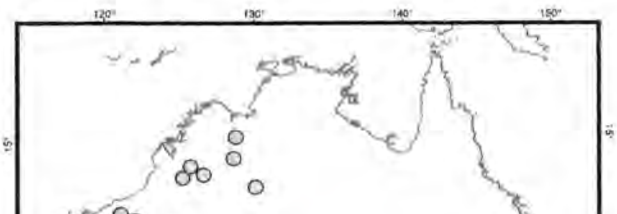

Figure 11: Diagrammatic map showing the location of Australite strewn fields (from McNamara & Bevan, 1991)

Nearly 5000 meteorites have been recovered worldwide (Arnett, 2004). Unfortunately for prospective collectors, Australian Federal laws protect meteorites found in Australia and it is an offence to export one without a permit. Meteorites found in some states (including Western Australia, South Australia, and Northern Territory) remain the property of the Government and must be lodged with an appropriate Museum. The finder may keep a meteorite recovered in other states, although it is advisable to check with local authorities before beginning a search.

Tektites

Tektites are small, often aerodynamically shaped, glassy objects that are found in large numbers throughout Western Australia (see Figure 11). Their origin continues to be the subject of research and debate, but consensus is that they are impact melt ejected from terrestrial impact craters (French, 1998; McNamara & Bevan, 1991). The regions in which tektites are found are called **strewn fields**, and Australian tektites are referred to as **Australites**. Other strewn fields are located in Africa, Europe, and North America, and each of these has been linked, with varying degrees of confidence, to known impact structures of similar ages (French, 1998). The impact responsible for the Australian strewn field is yet to be located, although recent work (Schnetzler, *et al*, 1999) suggests the structure may be located off the coast of Vietnam, in the South China Sea.

Searching for tektites is a rewarding pastime and, unlike meteorites, the finder may legally keep any recovered specimens (except those recovered in the Northern Territory that, like meteorites, remain the property of the Government).

Yarrabubba Impact Structure

Introduction

The Yarrabubba Impact Structure was first reported in 2003 following recognition by Francis McDonald, John Bunting and Sara Cina (McDonald, 2003). Much of the following description is based on that paper and on discussions with John Bunting (Pers Comm, June 2004). It is a deeply eroded core of a large impact for which little evidence of the actual structure remains. Present evidence of the impact points to three concentric structures, respectively 11 km, 25 km and 40 km across.

Location

The apparent centre of feature is located 70 km south-southeast of Meekatharra, and about 10 km southeast of Yarrabubba Homestead, at Latitude 27° 10'S and Longitude 118° 50' E (See Figure 13). A colour satellite image of the structure is presented as Figure 17. It is on the Yarrabubba Pastoral Lease.

The area of the Yarrabubba Impact Structure is mostly underlain by young alluvium of ill-defined watercourses and flats, with several low hills of granite and a rock like a fine-grained granite (termed *granophyre*).

The alluvium is dominated by red-brown sand, much being deposited from sheet-wash, overlying clay hardpan, with areas of massive calcrete and limestone, locally containing *chalcedony*.

The locally occurring granite was noted during mapping by Geological Survey and Bureau of Mineral Resources geologists in 1979-80 (Williams, 1984) as being an unusual type, and was named the Yarrabubba Granite. It is restricted to the area of the Yarrabubba structure. The granite is pale pink and coarse-grained and contains, in addition to quartz and feldspar, both black (biotite) and white (muscovite) mica. The muscovite was noted as being unusual in appearing to be formed from chemical reactions between hot aqueous solutions and pre-existing biotite. The granite contains many veins of quartz, pseudotachylite, and *pegmatite*.

A distinctive rock that occurs at Barlangi Rock and several other outcrops is the Barlangi Granophyre. The original geological mapping identified the rock as a normal volcanic one, with a pink colour, and consisting of scattered coarse grains of quartz and feldspar in a fine-grained matrix. It also contains scattered pieces of the nearby Yarrabubba Granite, in masses ranging from a few centimetres across to 0.4 metres across.

Description

There is neither a clear crater nor feature that could be considered to be the remnants of a crater. A broad alluvium-filled valley forms an arcuate shape around the granite outcrops, extending from Yarrabubba Homestead in the northwest to the eastern side Barlangi Rock (see Figure 17). It is possible that this shape may be related to the effects of the impact on rocks well below the original crater, but it may also be a coincidental product of long period of erosion and weathering.

Detailed features that support the hypothesis of an impact structure include shatter cones and mineral grains in the rocks that have been affected by extremely high-pressures, likely to have been caused by shock impacts.

Regional aerial magnetics readings collected over the feature (by the Geological Survey of Western Australia in 2001) were reprocessed (by Geoscience Australia) for the MacDonald *et al* study, and enhanced to bring out rather subtle evidence for the impact structure. The image generated (Figure 6 of their paper) shows a nonmagnetic zone 11 km east-west and 15 km north-south within a area of very complex and highly variable magnetic patterns. In the centre of this zone is a ring, 4 km east-west and 2 km north-south, formed by a magnetic pattern caused by slight increases in the magnetic strength of the rocks. This was found to coincide with the contact between the Barlangi Granophyre and the Yarrabubba Granite. Extending further out from the inner nonmagnetic zone, to a diameter of about 25 km to the north and 40 km to the southwest, is a zone with subdued magnetic patterns when contrasted to the patterns further out yet again.

There are many descriptions of impacts elsewhere in the world that show they demagnetise the rocks immediately under the crater, and a similar phenomenon is apparent at Yarrabubba. The central ring is attributed to remagnetisation of rock that had melted in the impact as it cooled after the impact (Bunting, pers. comm.). The outer zone with subdued magnetic patters may reflect a reduction of the magnetic strength of the rocks under outer parts of the original crater.

Age

Macdonald *et al* (2003) interpreted a Proterozoic age for the impact, implying it was formed between 2600 Ma and possibly 1800 Ma. This range is based on the crystallisation age of the granites that were in the target rocks and the inferred ages of dolerite dykes that cut the structure and hence postdate the impact. Cassidy *et al* (2002) reported a single zircon crystal that may give some indication of the age of crystallisation of the impact melts.

The antiquity of the impact means there has been a large amount of erosion that has removed the crater and potentially much rock since it was formed.

Related features

The Barlangi granophyre occurs at Barlangi Rock, within the granite a kilometre west, and as several dykes 4 km NNW of Barlangi Rock. It shows faint flow-banding adjacent to its contact with the granite. McDonald *et al* consider this to be an impact melt that was injected into the overlying granite as radiating sills. The Yarrabubba Granite is unusual in chemical composition when compared with other granites of he Yilgarn Craton, and they believe it may represent impact-related *metasomatism*.

Size & nature of impacting body

This is possibly one of the oldest impact features known on Earth. There is no evidence of an impact breccia, and the Barlangi Granophyre is not considered to be a crater-filling impact melt, but it intruded into the surrounding rock well below the former crater.

It is not currently possible to deduce the depth of the present rocks below the former impact level. However, it can be assumed that considerable erosion has occurred since the crater formed. MacDonald *et al* suggest that as much as 20 km of erosion may have occurred, although this is a speculative figure.

Shoemaker Impact Structure

Introduction

The Shoemaker Impact Structure was first described by Butler (1974), who named it the Lake Teague ring structure. He suggested it might have formed as either the result of granite intrusion or an impact event. Bunting *et al* (1982) carried out systematic mapping in the area and recognised the presence of shatter cones and PDFs. However, they ascribed these structures to a cryptoexplosive event (a hidden volcanic explosion) rather than impact origin.

It was not until Eugene and Carolyn Shoemaker carried out fieldwork during 1986 and 1995 that the impact origin of the structure was confirmed. Sadly, Eugene Shoemaker died in a car accident on 18 July 1997, during a geological field trip in Australia. In commemoration of his life and contribution to astrogeology, the Lake Teague ring structure was renamed the Shoemaker Impact Structure in 1998. Pirajno (2002) and Pirajno *et al* (2003) have recently completed detailed investigations of the structure, and this discussion is largely based on the latter work. Readers are particularly referred to Franco Pirajno's report and map, a copy of which has been provided to all excursion attendees.

The Shoemaker Impact Structure is a deeply eroded structure, (Pirajno *et al* suggest that 2 – 3 km of overlying rock may have been removed by erosion) and as a result we now observe rocks that were deep below the original crater floor. Estimates for the original crater diameter range from 36 to 90 km, although the structure has been formally assigned a diameter of 30 km, which corresponds to its visible extent. The structure may also have been tilted slightly to the northeast by *tectonic* activity.

Location

The Shoemaker Impact Structure is located at 25°52'S, 120°53'E, on Cunyu Station about 100 km northeast of Wiluna. A locality map is provided on (Figure 14), and a colour satellite image is provided on Figure 18. Geologically, it occurs at the southern edge of the Earaheedy Basin. However, it is only about 5 km from the northern margin of the underlying (older) rocks of the Yilgarn Craton, which are exposed at centre of the structure as a consequence of the impact's central uplift.

The structure is easily identified in the field because it interrupts the prominent line of hills of the northwest trending Frere Range, which rise about about 50 – 70 m above the surrounding plain. Two concentric rings of low hills, also consisting of Frere Range rocks, further define the shape of the structure. The outer ring is best developed in the southwest, and poorly developed to the northeast. Between the rings are situated the ephemeral Lake Nabberu, Lake Teague, and Lake Shoemaker.

Description

The two rings that define the Shoemaker Impact Structure are composed of sedimentary rocks of the

Yelma, Frere, and Chiall Formations. The Yelma Formation comprises up to 500 m of shale, sandstone, and siltstone, which were deposited in a shallow ocean. Overlying this is the Frere Formation, which is about 600 m thick and consists of layers of granular iron rocks separated by iron rich shales, siltstones, and minor carbonates. The iron rocks consist of chert, iron oxides, and jasper. (Chert and jasper are two related, amorphous forms of silica (quartz): jasper is essentially an iron rich chert variant.) The Chiall Formation is the uppermost unit, and comprises about 1000 m of siltstone, shale, and mudstone, with some layers of sandstone and breccia.

The area is structurally complex and is represented by an outer ring anticline and an inner ring syncline. A complex sequence of faulting, some of which contains quartz veins, has also occurred. In the eastern portions, thrusting and shearing introduce additional complexity. Outside the structure, radial quartz veins appear to converge towards the centre.

Rocks of the Teague Granite mark the uplifted core of the Shoemaker Impact Structure, which has a diameter of about 12 km. This unit consists of two types of granitoid rock (a syenite and a quartz syenite), which are both medium grained and brick red in colour. Quartz veinlets, microfractures, and millimetre-wide microbreccias containing fractured grains of quartz, feldspar, and amphibole cut the Teague Granite; the microbreccias may represent pseudotachylite veinlets. The Teague Granite has also undergone chemical alteration and is enriched in rare earth elements when compared to other, similar granitoids.

Age

The age of the Shoemaker Impact Structure is poorly understood, largely because the rocks have undergone a complex sequence of thermal events over time. A number of different isotopic age dating methods have been used on samples of the Teague Granite, and these provide us with widely varying age estimates. The techniques work by measuring the relative proportions of a radioactive isotope and its breakdown products. If the rate at which the isotope decays is known, an age can be derived from the measured amounts.

Uranium–Lead dating from zircons extracted from the granite returned 2648 ± 8 Ma, which is interpreted to be the age at which the granite was originally crystallised. Rubidium–Strontium (Rb-Sr) dating on whole-rock granite samples returned ages of 1630 and 1260 Ma, which are interpreted to be 'resetting' by thermal events (1630 Ma) and intense weathering (1260 Ma). Argon–Argon (Ar-Ar) dating returned disturbed apparent ages of about 1300 and 1000 Ma, the latter age possibly being related to the emplacement of a dolerite sill on the northern edge of the inner ring at about 1070 Ma. Lastly, Potassium–Argon (K-Ar) analyses on clay minerals from the granite provided ages of 694 ± 25 and 568 ± 20 Ma. The K-Ar technique has previously been successful at determining the tectonic and thermal histories of sedimentary basins, but the two ages are inconsistent and do not provide a conclusive age for the impact event. However, the 568 Ma age may represent impact triggered hydrothermal activity and hence the age of the structure, possibly indicating a relatively young age.

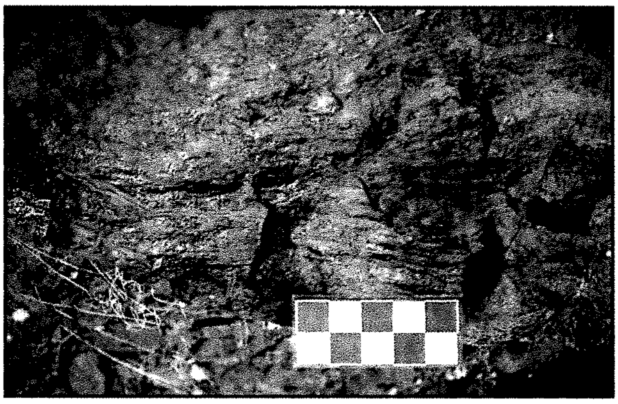

Figure 12: Horsetail feathering on poorly developed shatter cone, Frere Formation, Shoemaker Impact Structure, WA. MGA 290400E, 7145150N, Zone 51. Scale is 10 cm, individual squares are 2 cm

Related features

The most striking feature of the Shoemaker Impact Structure is the two concentric rings of iron-rich rocks, which mark a well-defined circular structure. Shatter cones up to 30 cm long occur in the granular iron rocks of the Frere Formation, as illustrated in Figure 12. The chert units of the Yelma formation, and the sandstone of the Chiall Formation, also contain shatter cones; in the latter case they are up to 0.5 m in length.

Planar fractures are found in quartz grains of the Chiall Formation sandstone, near the location of the shatter cones. Lastly, diagnostic PDFs are found in quartz crystals of the Teague Granite.

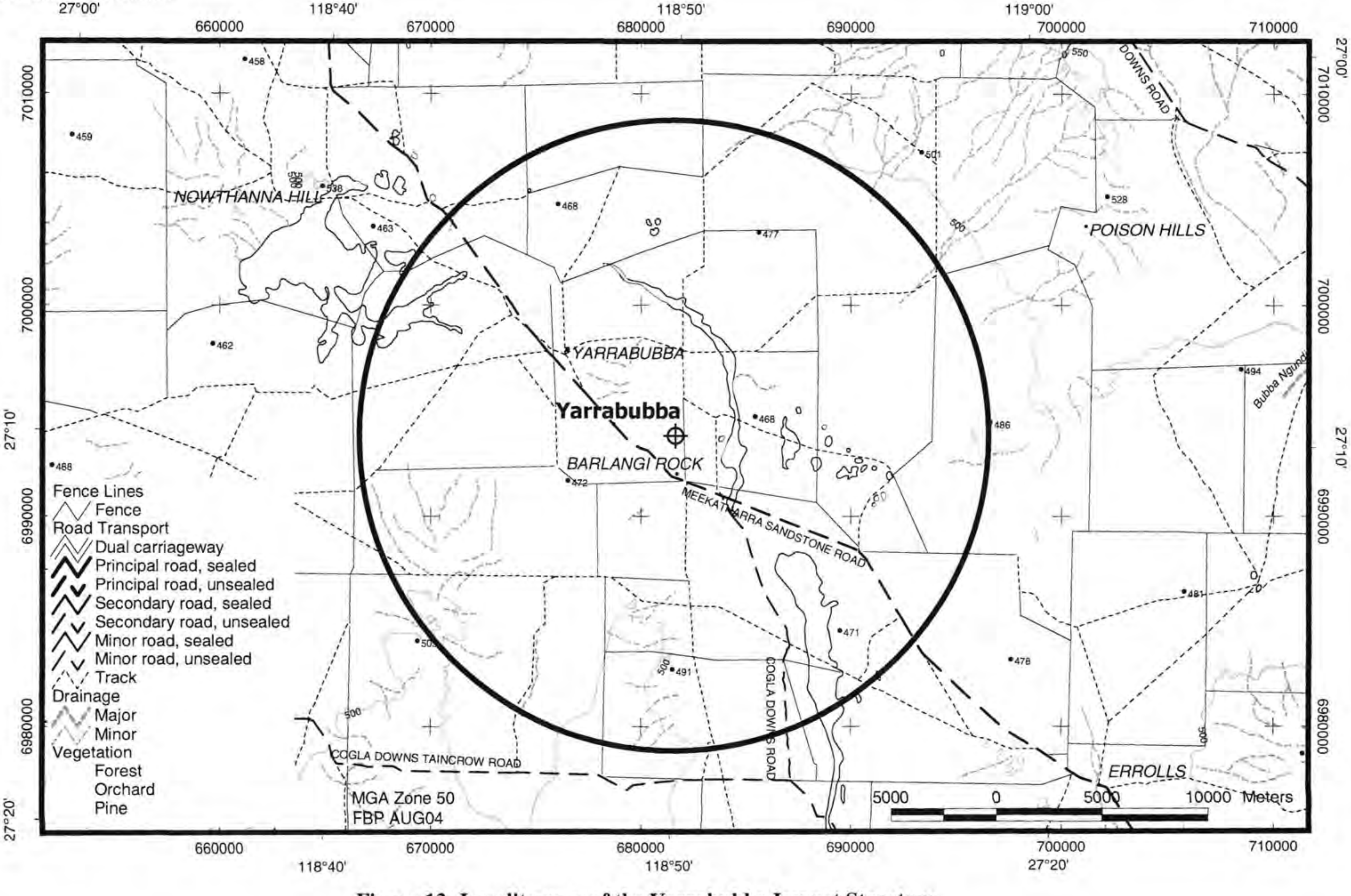

Figure 13: Locality map of the Yarrabubba Impact Structure.

Map data © Copyright Commonwealth of Australia (Geoscience Australia) 2003

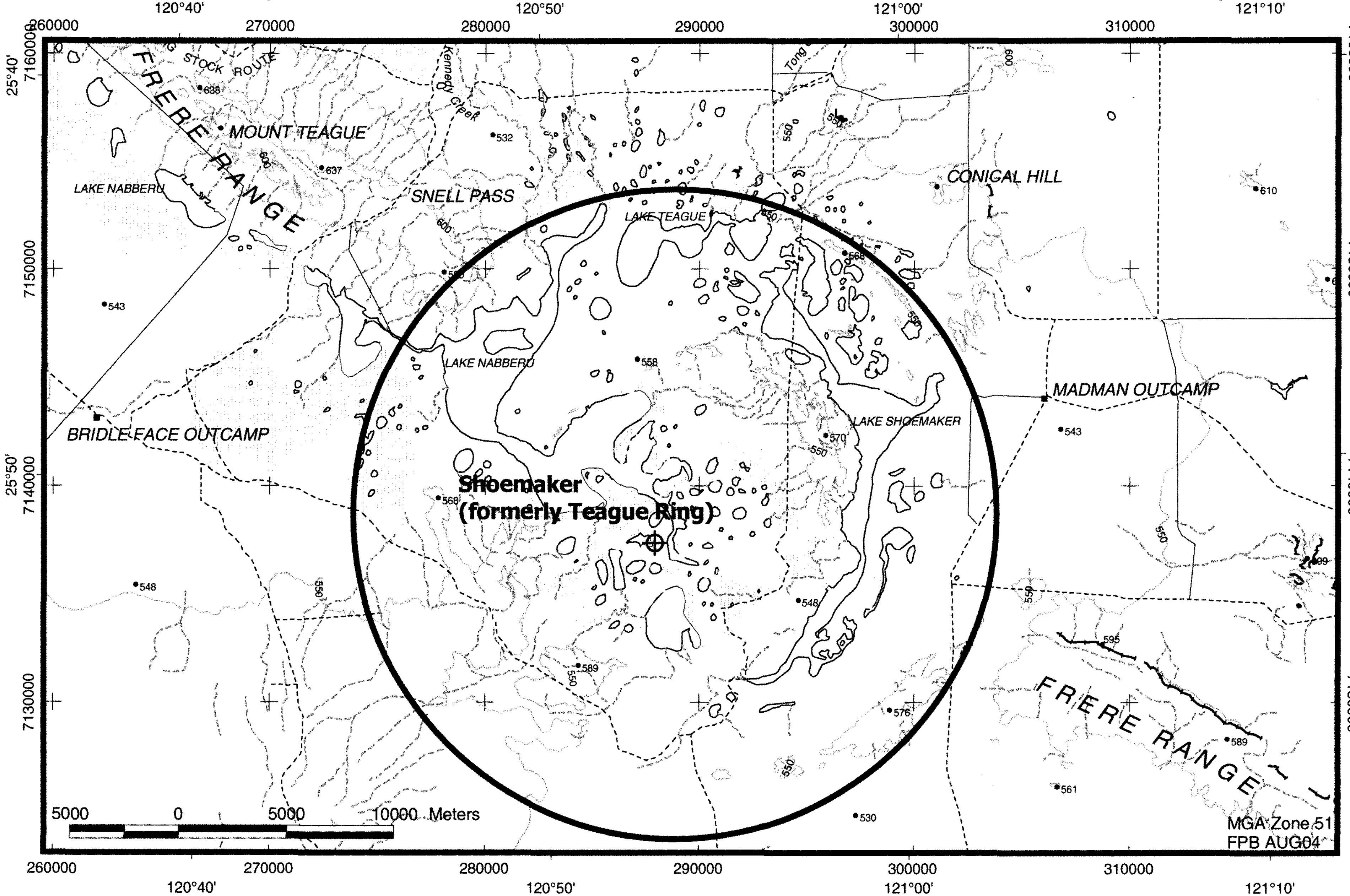

Figure 14: Locality map of the Shoemaker Impact Structure (refer to Figure 13 for map legend).

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In addition to the Shoemaker structure's obvious topographic signature, it also shows clearly in magnetic and gravity imaging. The technique of magnetic imaging is described elsewhere in this document; the circular shape of the structure shows clearly in such images. Gravity imaging works by measuring tiny changes in the Earth's gravitational force acting on a sensor, which are caused by variations in the density of the underlying rocks. The sensor is placed at regular intervals across the ground surface, and is so sensitive that its height above sea level must be surveyed to millimetre accuracy (changes in height affect the amount of gravity acting on the sensor). Once the gravity readings are collected and analysed by computer, an image is produced using colours to depict the variations in the gravitational force. The Shoemaker structure reveals a distinct gravity low, possibly caused by less dense fractured target rock.

Size & nature of impact body

Previous workers (see Pirajno (2003) for references) have defined approximate mathematical relationships between the diameter of the central uplift, the overall diameter of the structure, and the amount of vertical displacement within the central uplift. Based on the observed 12 km diameter central uplift, the amount of vertical displacement is estimated to be about 2.6 km. Although all evidence of the original crater has been eroded away, empirical work by French (1998) suggests that a projectile that created a 30 km crater would have been about 1.5 km in diameter.

Dalgaranga Meteorite Crater

Introduction and Location

Dalgaranga is a small penetration crater, located in the Murchison Region, 72 km northeast of Yalgoo and 74 km northwest of Mt Magnet (Lat 27°40'S, Long 117°17.5'E), as shown on Figure 15.

Bevan (1996) describes the crater, and much of the following description is based on his paper. Found in 1923 by G. E .P. Wellard, it was the first confirmed meteorite crater located in Australia

Description

Dalgaranga crater is 24 m across and a maximum of 3 m deep, and is one of the smallest craters known (only Haviland, located in Kansas, USA, at 15 m across, is reported as being smaller whereas the largest is Vredefort in South Africa at 300 km). It was excavated in slightly weathered granitic rocks of the Yilgarn Craton.

Uplifted blocks of granite surround the void on the southern part and ferricrete and granite on the northern part, giving a poorly formed rim. In the base of the crater is a mixture of rocks and soils, with the rocks having a blocky appearance and demonstrating a disrupted nature. The granitic rocks have pale colour and the appearance of mild bleaching, reflecting weathering of the rocks.

The meteorite was an "iron". Wellard is reported to have collected many meteorite fragments, though their location is not known. Collections were completed in 1959 and 1960 by H. H. Ninninger and G.I. Huss of the American Meteorite Laboratory, and just over 1 kg of meteorite fragments were located.

The meteorite is classified as a *mesosiderite* stony-iron, with two analyses of 8.8% nickel and 10.27% nickel in the iron part. Gallium was measured at 15.5 and 12.7 ppm, and iridium at 4.2 and 4.99 ppm. The fragments show *Widmanståtten* patterns, typical of slow crystallisation of the metal from the molten state.

Age

Eugene and Caroline Shoemaker (Shoemaker and Shoemaker, 1988) quote a maximum age of about 27 000 years, although there is a potentially large degree of uncertainty in this age estimate.

Size & nature of impact body

The total quantity of meteoritic iron found is the order of kilograms, mostly in masses of grams to a few tens of grams.

Specimens of purportedly Dalgaranga meteorite are currently being offered for sale on the World-Wide Web. Three sites located in July 2004 had gram-sized samples at prices of between $14 and

$42/gram (in contrast gold currently has a market price of about $17/g).

Yallalie Impact Structure

Introduction

Yallalie is a buried structure, located 30 km northwest of Moora and about 170 km north of Perth (See Figure 16 for a locality map and Figure 19 for a colour satellite image). Although it is concealed by younger sediments, there is a slight circular depression overlying it with *centripetal* drainage that may reflect the structure. No evidence of meteoritic material or of shock-metamorphic effects on rocks has yet been found, and until such confirmation is located, it is regarded as a probable impact feature.

Yallalie is well described in Dentith *et al* (1999) and much of the following description is based on that paper.

Location and background

Yallalie is located on the Dandaragan Plateau midway between the settlements of Moora and Badgingarra, east of the Gingin Scarp and west of the hardly discernible Darling Fault. The area has rolling hills with maximum relief of up to about 200 m. It is located near the divide between the west-flowing drainage of the Hill River and the south-flowing Moore River. In the immediate vicinity of Yallalie, the drainage is into the headwaters of Minyulo Brook. This stream flows southwestward and loses its identity in flood-outs on the sandy Northern Swan Coastal Plain inland of the coastal settlement of Wedge Island, about 50 km from Yallalie.

Ampol Exploration first located the Yallalie structure during its investigations of the petroleum potential of the Perth Basin in the 1980s. Seismic imaging showed an anticline at the site that was interpreted to be a likely reservoir structure for oil or gas, and Yallalie 1 oil well was drilled to test for the presence of these hydrocarbons. The well did not intersect hydrocarbons, and the company released its exploration information because it recognised the possibility of the structure being of meteoritic origin.

Description, geological setting and geology

Yallalie is identified on the ground as a broad, gentle-sided depression some 120 m deep and possibly as much as 20 km across. The lowest point is about 2.5 km south-southeast of the centre of the structure, sited at a small ephemeral lake, which is the focus of the centripetal drainage in the depression. Intermittent overtopping from this lake takes runoff out of the depression into Muthawandry Creek that has breached the "rim" to the south. Muthawandry Creek, in turn, drains into Minyulo Brook.

Geology

The structure is formed within Perth Basin sediments that are about 10 km thick in the vicinity of Yallalie. The sediments were deposited in very mixed environments, ranging from marine (sands to silts), to *fluvial* sediments (silts to clays with some sands), including some deposited in swamps (mostly silts with lesser clayey sediments). In parts the sequence includes coal and thin limestone. Younger parts of the sequence are dominated by continental sediments, consisting mostly of silts and with more coal seams. The sediments range in age from Permian (about 250 Ma) to Cretaceous (about 150 Ma). However, at the top is a local sequence of much younger Pliocene sediments (about 5 Ma).

Subsequent to the deposition of the Perth Basin, the sediments have been subject to large amounts of faulting, mostly with northerly trends and with varying amounts of vertical offset.

In the vicinity of Yallalie, the sediments remain largely horizontal, although a depression with an inner domal structure, where the beds dip at a few degrees, forms the potential impact structure at depth. There are no surface indications of disruption caused by an impact. However seismic surveying shows the nature of the impact structure.

Deformed rocks first occur at a depth of 239 m in the Yallalie 1 oil well, and consist of late Jurassic rocks. Ampol Exploration had noted in an unpublished report that in other nearby bores, deformed rocks appeared to be of mid Cretaceous age. The deformed rocks continued to a depth of 1562 m, and from there to the base of the hole at 3321 m the bedding was not disturbed. Detailed stratigraphic and palaeontologic analysis of the drilled sequence and comparison with other oil wells and water bores in the district suggests that the sediments in Yallalie had been uplifted by the order of 700 m.

Detailed examination of quartz grains from the site failed to show any deformation that could be attributed to a meteorite impact, such as planar deformation fabrics. Some unusual fabrics were identified by Vic Gostin of Adelaide University that may have been induced by an impact, but they could also be caused by brittle fracturing of the grains at pressure much lower than the shock of a meteorite impact.

Seismic surveying

Seismic surveying generates cross-sections through the ground, based on reflection of ground vibrations produced at the land surface. Layering in the rocks, where adjacent beds have contrasting physical properties, reflect the vibrations back to the surface where they are recorded by geophones. The vertical scale of the cross-sections is usually time, measured as the time taken for the ground vibrations to travel from the source on the surface down to the reflecting horizon and back to the receiving geophones. They can be considered as approximating the layering of rocks below the ground surface.

The vibrations travel at the speed of sound, and in the sediments of the Perth Basin would be transmitted at speeds of the order of one to a few thousand metres per second. Seismic sections over Yallalie show (refer to Figures 7 and 8 in the paper by Dentith *et al*, 1999) a zone of chaotic reflections from near the surface to a depth equivalent to about 1.5 second two-way travel-time (TWTT), about 12 km across and with a very sharp margin at the edge where they join the undisturbed surrounding rock. Below that is another 1.5 seconds of coherent bedding that is updomed, with a diameter of about 5 km. Below that, in turn, the indications of updoming continue to some 4 seconds TWTT. These are contained within a large bowl-shaped hollow about 12 km across, described by Dentith *et al* (1999) as a sombrero shape, which is a distinctive form of complex impact craters. The chaotic zone is interpreted as the zone within which a meteoritic crater was formed. The updomed rocks constitute the central uplift structure that forms in many meteorite craters. The flat-lying bedding below the structure shows that whatever caused the disruption and updoming did not arise from processes within the Earth, such as faulting or through tectonic activity, but came from above.

With a diameter of 12 km, the Yallalie structure can be considered as a possible complex impact structure. Other evidence, such as the sombrero structure observed in the seismic data, or the concentric anomalies observed in the magnetic data, support this conclusion. The sharp cut-off against the surrounding sediments is inferred to indicate faults bounded the structure, again typical of complex craters.

No material that could be attributed to a meteoritic impact has been found in outcrops in the vicinity of the structure. However, a breccia outcrops in a road cutting at Mungedar, located 11 km west of the centre of the structure. This is described by Dentith *et al* (1999) as consisting of deeply weathered greenish rock with blocks up to more than one metre across. The rock is now clayey and porcellanous of uncertain affinity.

Magnetic interpretation

The Earth's magnetic field is affected by the amount of magnetic material (mostly magnetite) in rocks below the surface. Routine surveying of the variations of this field is done with aircraft flying at low levels (30 m or 60 m) on parallel lines spaced a few hundred metres apart. The results are contoured and digitally processed to reveal patterns that can be interpreted with respect to the rocks and breaks in the rocks below the surface. Likewise, very detailed measurements are made of smaller areas by measuring the variations with hand-held instruments over a regular grid on the ground.

Detailed measurements and interpretations of the magnetic images over Yallalie have been completed (Hawke and Dentith 2002). The images show several subcircular magnetic features. A magnetic high is located at the centre of Yallalie, surrounded by a ring that is a magnetic low about 2 km across, surrounded in turn by a magnetic high 5 km across, then a low 7 km across. Another high over 8 km across a penultimate low at 10 km and finally an outermost high at nearly 12 km across that correlates with the outermost sign from the seismic interpretation. This series of magnetic highs and lows is interpreted to show a series of circular faults that reflect the terraces that formed as the crater walls collapsed into the transient crater excavated during impact.

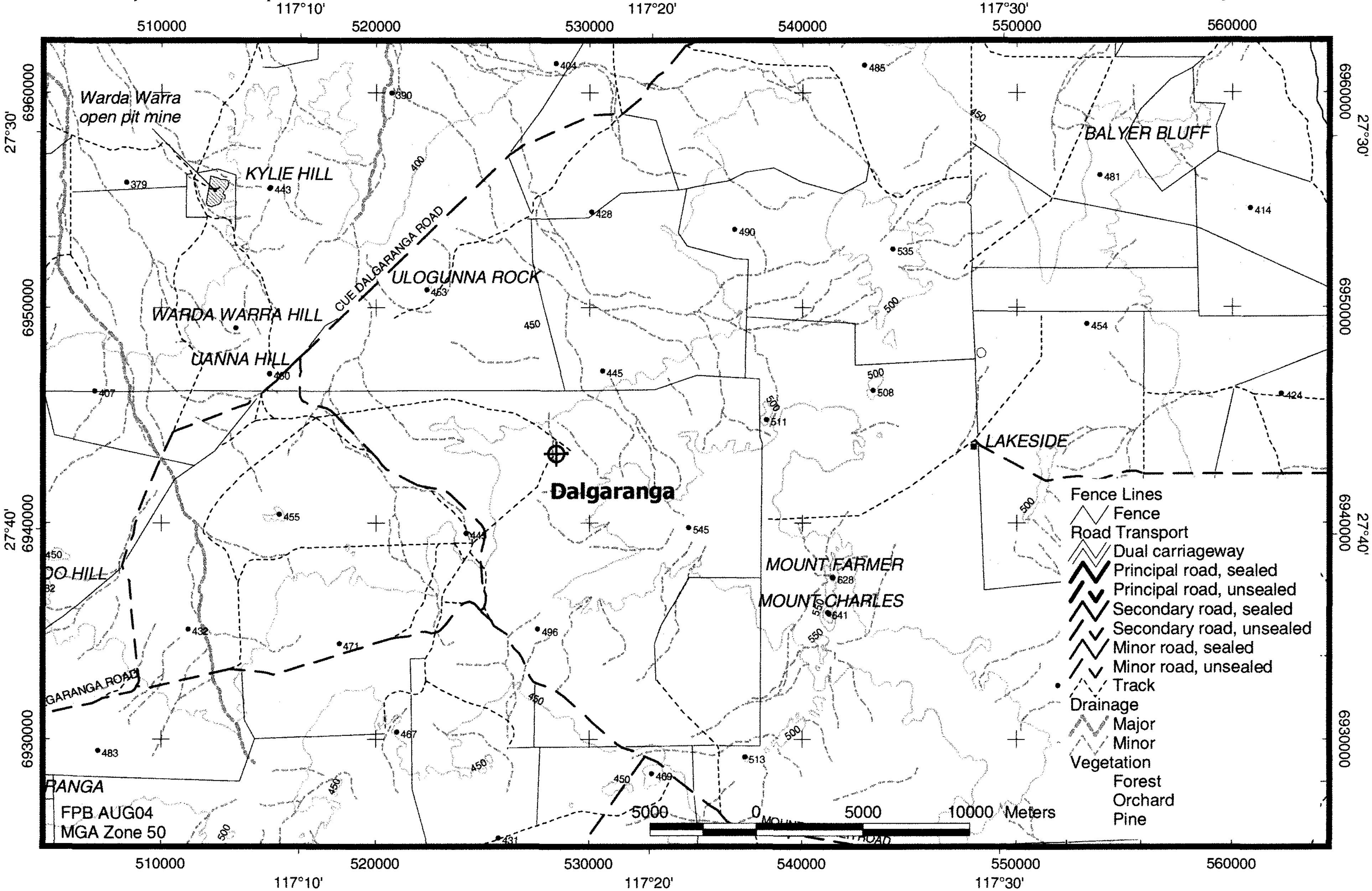


Figure 15: Locality map of the Dalgaranga crater.

Map data © Copyright Commonwealth of Australia (Geoscience Australia) 2003

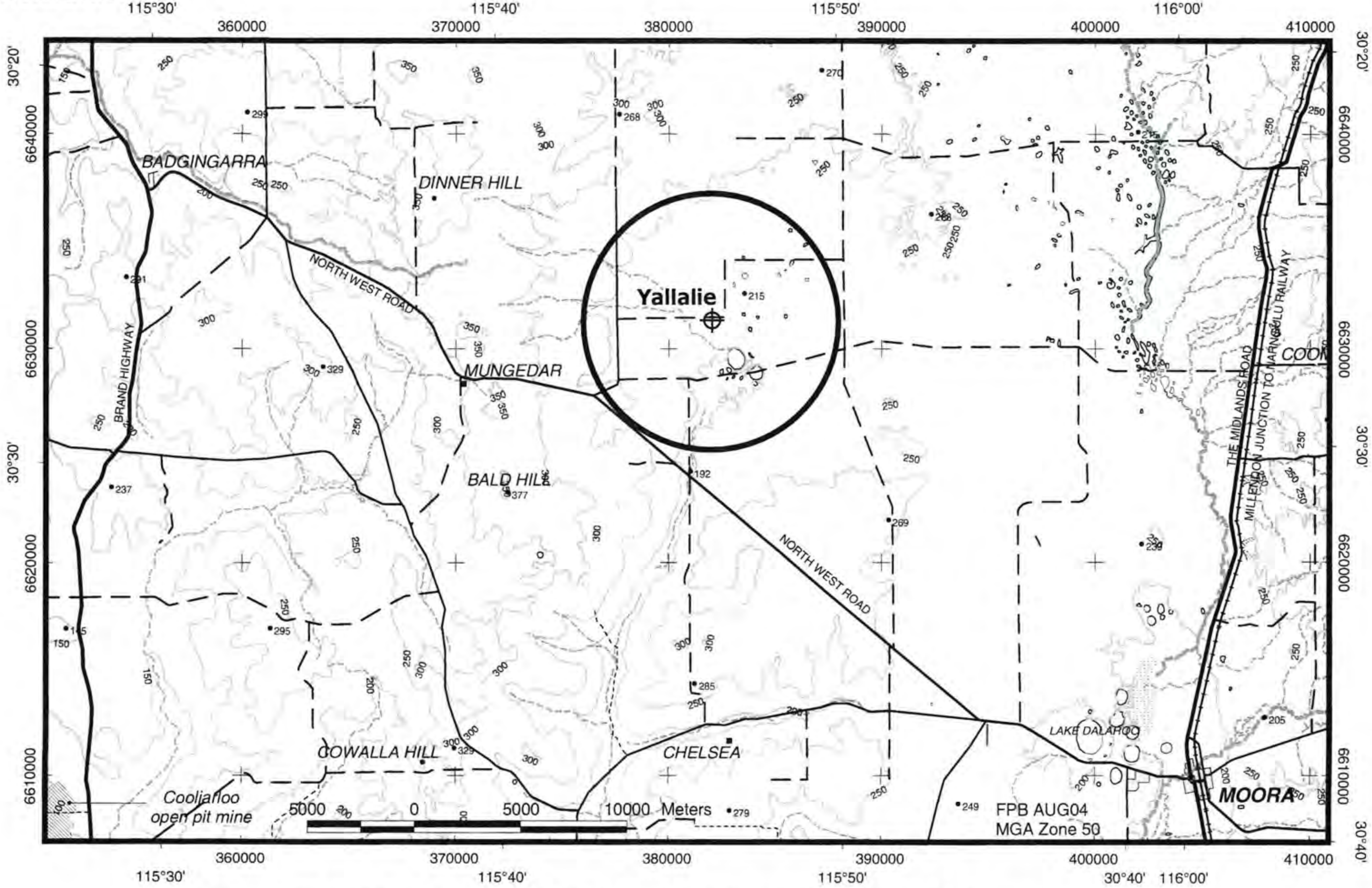


Figure 16: Locality map of the Yallalie ?Impact Structure (refer to Figure 15 for map legend).

Map data © Copyright Commonwealth of Australia (Geoscience Australia) 2003

Age

Dentith *et al* (1999) report that the youngest sediments apparently affected are Cretaceous in age, and there are undisturbed Pliocene-aged sediments overlying the deformed rocks in Yallalie 1. Therefore, they conclude that the disturbance of the bedding occurred between these times, and this indicates that the structure was formed between about 65 Ma and 5 Ma. Additional work is needed to determine a more accurate time.

Size & nature of impact body

Dentith *et al* (1999) report they had conducted a number of microscopic and chemical investigations to ascertain if a direct meteoritic cause could be identified, and if so the nature of the impactor. Work done included detailed examination of a number of samples from water bores that may have intersected the structure, and using extremely sensitive chemical techniques to test for possible chemical signatures of an extraterrestrial source. They were all unsuccessful. Therefore, without knowing the nature of the impactor, it is difficult to model the size of the body (and that still requires the confirmation that it was an extraterrestrial source).

An impacting body colliding with the Perth Basin sediments would have hit a weakly consolidated pile of sediments that were porous and with a water table probably near the land surface. It is even possible that the sediments were still submerged. The nature of such a target would have absorbed much kinetic energy, reducing the size and intensity of the shock wave effects.

It seems that there has been significant erosion since the structure was formed. Dentith *et al* (1999) conclude that only the deeper parts of the structure remain, and that those are buried below younger Pliocene sediments. The 700 metres of central uplift they interpret requires at least that amount of erosion off the upper surface. They conclude there is reason to interpret more that one period of erosion since the time of formation.

Route description

Day 1

The Perth Observatory is located on the Darling Range, and is underlain by a deep-weathering profile that overlies granitic rocks of the Yilgarn Craton. The deep-weathering profile is capped with a ferricrete horizon, referred to as a *duricrust*.

From the Observatory we head out past Mundaring Weir to Mundaring and on to Northam from where we turn north to Goomalling, Wongan Hills, Dalwallinu and to the last town for some distance at Wubin. From the start to Goomalling the rocks are included in the Jimperding Complex, a group of metamorphosed sediments and volcanic rocks with a scattering of *mafic* intrusive rocks. At Wundowie is a mafic intrusive that contains a large deposit of the metal vanadium, and to the north is a small greenstone belt. The hilltops have lateritic duricrust cappings.

Once past Goomalling, the Yilgarn Craton is dominated by granitic rocks of various types. These areas are prone to salinity problems, and salt-scalds are common. These are areas where the groundwater table has risen to near the land surface, killing the vegetation and leaving bare soils. This has occurred because humans have changed the equilibrium that existed prior to clearing of the native vegetation. When the areas were covered in native vegetation, the amount of water in the soils was in balance between rainfall, run-off and evapotranspiration losses from the plants. Now the cereal crops and fodder grasses only grow for several months each year, and so the amount of water lost by evapotranspiration has decreased, adding water to the water table, and causing it to slowly rise to the surface. Most of the water is saline because of sea salt that has accumulated over geological periods. The salinity-affected areas will increase until a new equilibrium is established, and the balance will occur through simple evaporation from moist areas rather than, as occurred previously, through evapotranspiration losses.

Through to Wubin the route is mostly past well-cleared wheat paddocks that are used also for sheep-raising. These areas are underlain by granites of the Yilgarn Craton of Archaean age. Locations of the low hills and broad gentle valley are controlled by the weathering of the granitic rocks. Areas where the granite is more prone to weathering form the valleys, while areas of more resistant rocks form the hills. Granites are liable to develop major jointing when they cool, forming zones that are more susceptible to weathering. If well-developed over longer distances, these early joints can lead to the generation of straight-floored valleys.

About 30 km past Wubin the road crosses the first of a number of *palaeodrainage* valleys the route intersects. This one is an area of small unnamed salt lakes between Lake Goorly to the south and Lake Monger to the north. Prior to Eocene times, there were well-developed, integrated river systems draining the Yilgarn, with water flowing from them to the ocean. At that time, the World's climate was warmer than now, and precipitation was much greater. After Eocene times, the climate cooled, the rainfall decreased, the river flows dropped and the channels became clogged with sediment. More recently, these low-lying areas, to where saline groundwater has percolated, have become evaporation pans where the salt has precipitated. This channel is part of the Lake Moore Palaeochannel.

From the lakes onward we enter pastoral country, leaving the cleared private farmland behind, and entering bushland, used for low density sheep and cattle grazing.

Some 70 km from Wubin, the land rises gently, and the density and diversity of the vegetation increases as we cross from granite onto greenstone. This is the Mount Gibson Greenstone Belt, host to the Mt Gibson goldmine, located about 5 km to the east of the road. Numerous small goldmines occur scattered through the bush. Just east of Mt Gibson is the site of the Karpa Spring gold fraud. In 1990 three prospectors sold what was apparently shaping up to be a fabulously rich and large gold deposit for $6 million. The company purchasing the prospect could not find any gold! After the company reported an alleged fraud, and following a long investigation, the prospectors were arrested, tried and found guilty. However, in 2001 an appeal was heard and the earlier decision was overturned. The question now remains as to who committed the fraud by salting drilling samples. It remains as one of Australia's largest unsolved mining fraud cases.

About 20 km northeast of the gold mine is Mt Singleton, a large domed hill rising to 698 m above sea level. This is being considered for a new astronomical observatory to replace the Bickley facility, but run as a remote observatory from Bickley. The distance from Perth would protect it from the light pollution now affecting Bickley, and the altitude would elevate it above a large amount of atmospheric interference.

After the settlement at Paynes Find, still on greenstones, the road crosses granite almost to Mt Magnet. Lake Mongers, as noted earlier, extends almost to Mt Magnet, illustrating the extent of some of the palaeodrainage systems on the Yilgarn. North of Mt Magnet, the road crosses Lake Austin, a centre of internal drainage. This lake has significant deposits of gypsum on its shores, and the road passes next to *lunettes* of gypsum.

North of Cue, our route will leave the Great Northern Highway to head east towards Yarrabubba. However, it is likely we will camp before getting to the feature.

Day 2

The day is expected to start with a short drive to Yarrabubba Impact Structure. It is intended to inspect the outcrops at Barlangi Rock and at outcrops about 4 km north. At Barlangi Rock we will see the Barlangi Granophyre, part of the melt rock generated during the impact. At the unnamed outcrops to the north there are shatter cones or sheets, brecciated granite, pseudotachylite veins and relationships between these various rock types to observe.

After leaving the site, we will drive to Meekatharra and then to Wiluna. The Meekatharra-Wiluna road starts across granite country with soil-plains. However, about 40 km out, the country changes and we drive across the *unconformity* at the base of the Earaheedy Basin.

The Earaheedy Basin, consisting of sandy to shaly sediments and limestone, produces a totally different *lag deposit* than the granites of the Yilgarn and consequently different vegetation. The soil surface becomes redder and the soil contains scattered sandy pebbles and fragments. The road continues along these sediments nearly all the way to Wiluna where they are then replaced by Yilgarn Craton rocks.

Leaving Wiluna, the road continues along flat plains country overlying Yilgarn Craton granites and with some greenstone belts, heading northeastward towards the Shoemaker Impact Structure. It is probable that we will not get to the Shoemaker this day, although if we do it will be a bonus.

Day 3

As we approach the Shoemaker Impact Structure, the view from the higher ranges on the south side shows the overall size of the structure. It is quite difficult to appreciate the dimensions and nature of the impact that could create a crater that was obviously over 30 km across.

We may visit and observe

- Shatter cones in the Frere Formation on the northern margin;
- Teague granite in the central uplift. This contains mineral grains showing high-pressure or shock deformation fabrics (PDFs);
- Hydrothermal chert pods within the Sweetwaters Well member of the Yelma Formation; and
- Quartz veins arranged radially around SIS, located in the Yilgarn Craton granites to the SW;

Leaving Shoemaker, we head back towards Meekatharra for a campsite.

Day 4

Breaking camp, we will drive through the historic mining towns of Mt Magnet and Cue and head west from the latter. The country changes a little, with the soil-covered plains being pierced by granite hills, named inselbergs. These have smooth rounded sides, ranging from steep-sided to gently sloping. They can be regarded as little Ayers Rocks. They remain proud because firstly the granite is not well-jointed, and secondly the granite surface is protected from weathering by developing an outer rind of hardening. Granites fracture or become jointed as they cool from their original molten state. When overlying rocks are eroded off, weathering processes within soils near the Earth's surface convert some of the minerals to clays, and the former granites are then easily eroded. Weathering is accelerated by water seeping along the old joints and weathering the rock in three dimensions and not just at the upper surface. However, if the joints are well-spaced, this weathering is much slower, and unjointed masses of granite can then remain as rock. Some granites can be "case hardened" through the precipitation of quartz and iron minerals through the development of special conditions during the weathering process. If this occurs, the granites can remain as prominent, isolated hills within a large area that has totally weathered below the plain.

Walga Rock about 45 km west of Cue is a prominent granite hill. It has some conspicuous Aboriginal paintings, with one image of a sailing ship that has generated considerable debate regarding its Aboriginal authenticity, and if authentic, of how Aboriginals some hundreds of kilometres from the coast would have seen and then painted them here.

We will then drive to Dalgaranga Meteorite Crater. This is within a Crown Reserve for Management of Significant Geological Feature and vested in the Minister for State Development, as the Minister responsible for the Geological Survey of WA. At this small crater we will see the actual void created by the impact, the low rim and the apparent breaking out of rocks from the plain. Careful looking around the crater may locate meteoritic material, but if you do locate any, mark it. All meteoritic material is the property of the State and normally will reside in the Museum after proper collecting and documenting.

Leaving Dalgaranga, the route will be to the distinctive little mining hamlet of Yalgoo, and probably to a campsite on the way to Morawa.

Day 5

Through Morawa and Three Springs we will head to the Yallalie Impact Structure. This is not yet a proven impact, but the existing evidence is strongly suggestive. The structure is actually buried at a depth of nearly 240 m. However, there is a 12 km-diameter shallow hollow at the surface that seems to reflect the presence of the underlying structure and deformed rocks. Just to the west is a road-side cutting showing a breccia that is interpreted to have been caused by the impact.

Leaving Yallalie, the route will be back to Perth and the Observatory car park.

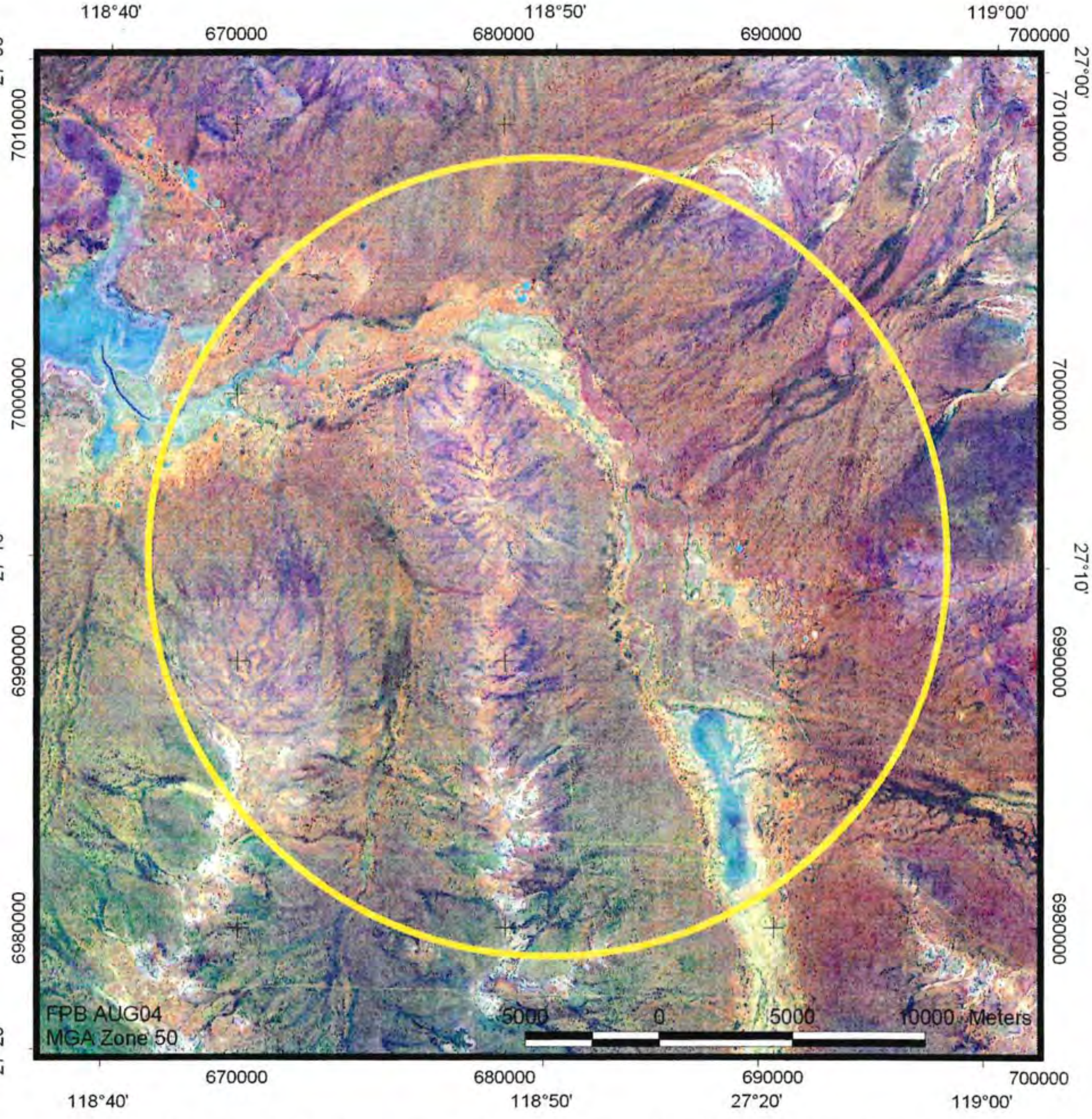


Figure 17: Colour image of the Yarrabubba Impact Structure
Scale 1:250,000 (4 cm equals 10 km)

Data courtesy of Global Land Cover Facility, University of Maryland

False-colour Landsat ETM+ scene acquired 31 July 2000. Image processing as for front cover image: Bands 7, 4, and 1 in RGB, sharpened with panchromatic image, giving an apparent resolution of 14.25 m.

The yellow circle marks a diameter of 30 km, which is the interpreted size of the structure. Note the absence of any clearly defined circular features. North-south trending pale brownish-white areas are hills of the Yarrabubba Granite (in the centre of the image) and of other granitic rocks elsewhere. The pale cyan-blue areas represent ephemeral salt lakes; one of which reveals an arcuate shape in the northern half of the structure. Fan shaped features around the edges of the image are alluvial fans, deposited by sheetwash.

The thin white line traversing the image from northwest to southeast is the Meekatharra – Sandstone Road; Barlangi Rock is situated at the sharp bend almost at the centre of the structure, just to the east of the Yarrabubba Granite.

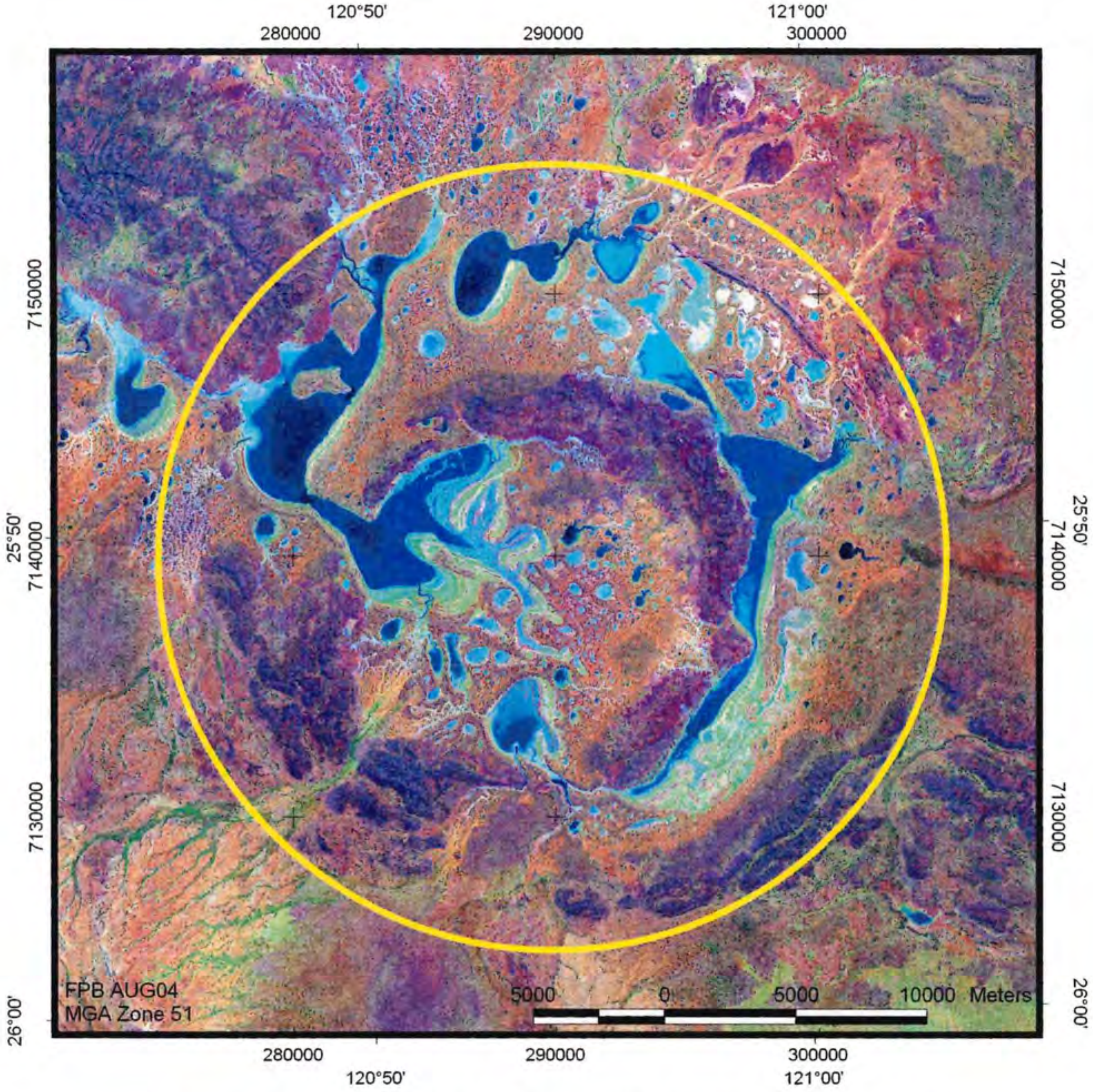


Figure 18: Colour image of the Shoemaker Impact Structure (SIS)
Scale 1:250,000

Data courtesy of Global Land Cover Facility, University of Maryland

False-colour Landsat ETM+ scene acquired 5 May 2000. Same dataset as front cover image: Bands 7, 4, and 1 in RGB, sharpened with panchromatic image, giving an apparent resolution of 14.25 m.

The yellow circle marks the interpreted 30 km diameter of the structure. Note that the SIS is not exactly circular and thus does not precisely fit the circle. Blue and cyan areas signify ephemeral salt lakes (blue areas indicate shallow water), green signifies vegetation, pale brown signifies bare soil, and the various shades of dark reddish brown signify exposed rock. In particular, the purple-brown rocks in the northwest and south-east of the image are the undisturbed portions of the Frere Range. The outer ring structure, composed of Frere Range rocks, can be clearly seen in the southwest, and the inner ring structure in the northeast. The hills in the southwest offer a fine vantage point from which to view the entire structure.

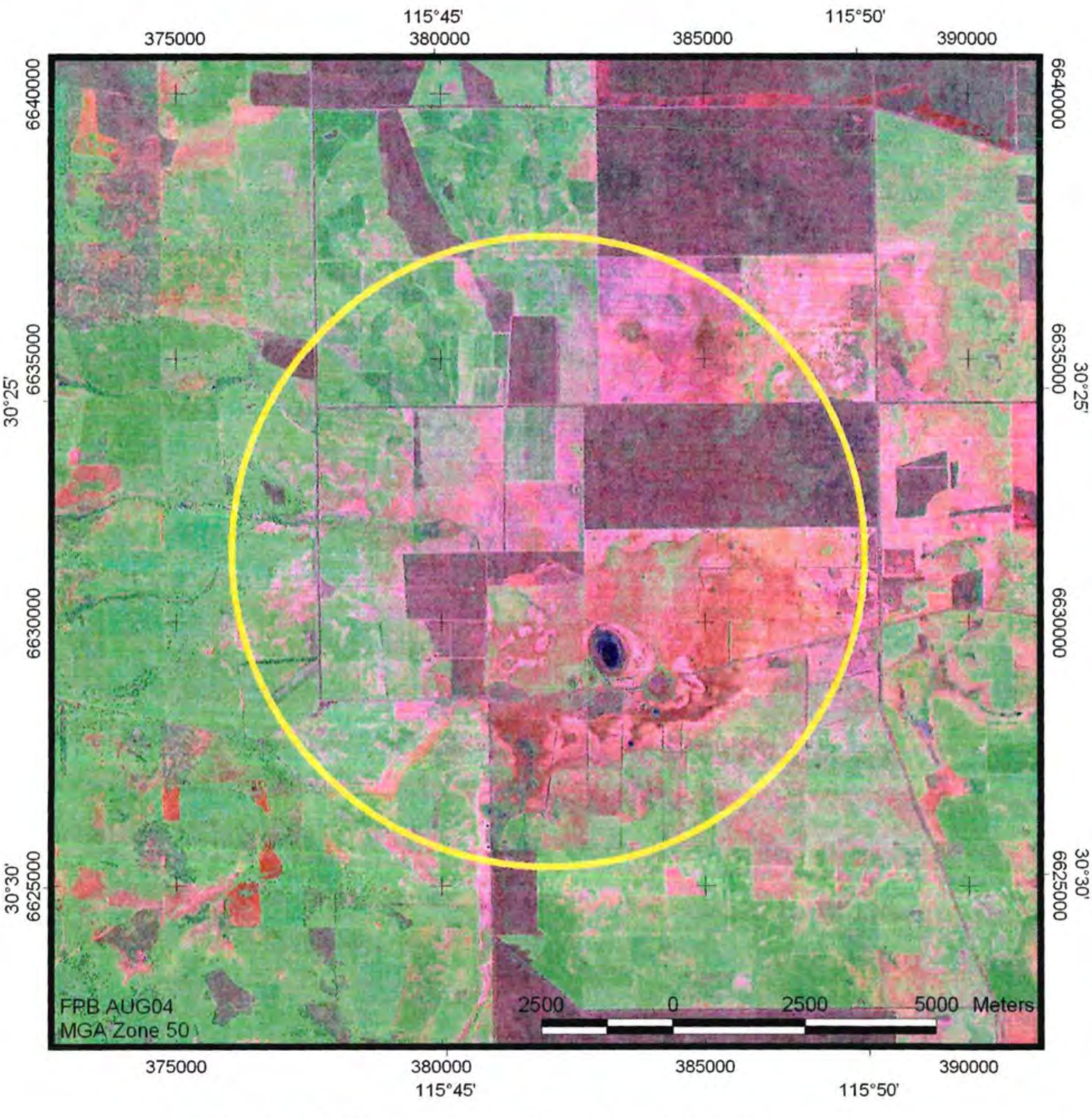


Figure 19: Colour image of the Yallalie impact structure
Scale 1:125,000

Data courtesy of Global Land Cover Facility, University of Maryland

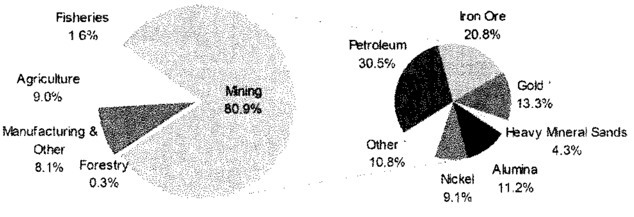
False-colour Landsat ETM+ scene acquired 17 August 2001. Image processing as for front cover image: Bands 7, 4, and 1 in RGB, sharpened with panchromatic image, giving an apparent resolution of 14.25 m.

The yellow circle marks the interpreted 12 km diameter of the structure. From the ground, this buried structure reveals no significant features except for a subtle circular depression, however when viewed with satellite imagery, a pattern of centripetal drainage lines, all feeding towards the centre of the structure, becomes apparent.

The checkerboard pattern seen on this image is indicative of farming activity. Green areas signify vegetation; the intensity of the green provides information on the type and vigour of vegetation within each land parcel. Shades of light red indicate bare soil, and dark greyish-red areas represent remnants of natural bushland.

Western Australia's mining heritage

Western Australia owes much of its prosperity to the resource industry, which is the biggest contributor to the State's GDP. In 2003 the total value of Western Australia's petroleum and mineral sales was $26.6 billion, making up just over 80% of the State's exports (Figure 20). To put this into context, the next biggest contributor was agriculture, which contributed 9% to the State's export sales income. The WA resource sector is also a major employer, with direct and indirect employment comprising 19% of the State workforce.



Source: ABS and DoIR
Includes $2.8 billion gold originating from States and Territories outside of Western

Figure 20: Western Australian export statistics, 2003 (from DoIR, 2004)

Over 480 resource projects operated throughout Western Australia in 2003, consisting of 770 operating mines extracting 50 different minerals. Gold features prominently in the State's mineral sales, falling third behind petroleum and iron ore, and our route, which takes us across the northern part of the Yilgarn Craton, passes many of these mines. In particular, active gold mining areas are found around Mount Magnet, Cue, Meekatharra, and Wiluna. Two notable exceptions to the dominance of gold on our journey are the Three Springs talc mine, situated at the western edge of the Yilgarn Craton near the town of Three Springs, and the lead-zinc-silver-copper mine at Golden Grove, about 55 km southeast of Yalgoo.

Western Australia has a long history of mining, which somewhat surprisingly began in the Kimberly and Pilbara regions. Gold was discovered near Halls Creek in 1885, and this was followed by discoveries in Mallina (in the Pilbara) in 1887, Nullagine in 1888, and Marble Bar in 1890. In the subsequent years, the discoveries found their way further south – at Yalgoo and other parts of the Murchison in 1891, and finally the familiar discoveries at Coolgardie and Kalgoorlie in 1892 and 1893.

Yalgoo was settled by prospectors on their way to the gold rushes at Cue and Mount Magnet. At its peak, it had seven hotels, which served a vast array of tents. The town started to decline in 1903 when the gold started to diminish, and the railway line that serviced the town was finally closed in 1978. One of the most unusual buildings in what remains of the town is the Dominican Chapel of St. Hyacinth, construction of which was completed in 1922.

The town of Cue, just over 200 km from Yalgoo, was once known as the "Queen of the Murchison", and it prospered during the gold rush of the 1890's after two prospectors picked up nuggets weighing 260 oz (about 8 kg; at $17/gram worth about $140 000) near what became Cue's main street. The town was proclaimed in 1894, taking the name of prospector Tom Cue, who registered one of the claims in the area. At one time the town, along with nearby 'twin' town Day Dawn, even boasted three newspapers. However, in typical goldrush style, Cue's fortunes were tied to gold production, and the town's fate was sealed when the last mine closed in 1933. A notable period of Cue's history is the time that Herbert Hoover spent working as a mining engineer, before moving on to become president of the United States of America. Nowadays, Cue is best known for its unusual architecture, particularly the Masonic hall.

The night sky – September 2004

Rotation of the sky

Because of the Earth's rotation, the sky appears to revolve once every 24 hours. This period is referred to as a **solar day**. However, because the Earth also completes one orbit around the Sun per year, the time taken for the **stars** to complete one revolution is only 23 hours 56 minutes. This period is called a **sidereal day**. A solar day is four minutes longer than a sidereal day because the Earth has to rotate a little further each day to compensate for its changing position relative to the Sun. On the other hand, because a sidereal day is four minutes shorter than a solar day, the stars will rise four minutes earlier each (solar) day, or an hour earlier every fortnight. Sky charts that are made for, say, 8 PM at the beginning of the month, must be used at 7 PM mid-month, and at 6 PM at the end of the month. Simple hand-held representations of the night sky called planispheres automatically compensate for this movement by allowing the user to dial-in the current time and date.

Measuring angles in the sky

Although the heavenly bodies occur at vastly different distances from Earth, it is convenient to imagine them as being projected onto a huge sphere with our observing location at the centre. Astronomers refer to this as the **celestial sphere**. The coordinates of objects on the sphere can therefore be specified in terms of latitude and longitude, much as they are on Earth. Astronomers refer to these coordinates as **declination** (equivalent to latitude) and **right ascension** (equivalent to longitude). Right ascension is somewhat different from longitude, however, as it is measured in hours (from zero to 24) and increases only to the east.

Since actual distances are not involved, the celestial sphere also provides a convenient means of measuring the separation of objects in the sky, simply by measuring the angle subtended by the objects. A hand, held at arm's length, provides a simple yardstick:

- The width of the index finger spans about 2°. Adding more fingers increases the angle in multiples of 2° for each finger.
- A clenched fist, excluding thumb, spans about 10°.
- An outspread hand, from the tip of the little finger to the tip of the thumb, spans about 20°.

Stellar magnitudes and star names

Stars vary greatly in brightness, and in ancient times they were ranked in six classes, with first magnitude the brightest and sixth magnitude the dimmest. This system was further refined in the 1850's using a logarithmic scale to quantify the difference between magnitudes; a change of one magnitude is defined as a 2.5-times change in brightness, and a change of five magnitudes corresponds to a brightness ratio of 100-to-1. It was later found that first magnitude stars contained too great a range of luminosities, and negative magnitudes were introduced to allow for greater variation. So, the brightest star in the sky, Sirius, has a magnitude of –1.4, and the dimmest stars visible with the unaided eye have a magnitude of around 6. Visual observing with a large telescope will resolve stars down to magnitude –25. On the other hand, Venus at its brightest has a magnitude of –4.4, and the full moon shines at –12.6 magnitude.

In 1603 Johann Bayer ranked the stars of each constellation in decreasing magnitude order, labelling each with a Greek letter followed by a genitive of the constellation name. So, the brightest star in Orion was named Alpha Orionis, the second brightest Beta Orionis, and so on. Despite some problems resulting from modern re-designation of some constellations (causing some stars to have the wrong genitive), or some stars being labelled in incorrect magnitude order, the system provides a convenient means of identifying bright stars, only about 150 of which have proper names.

Evening sky

These descriptions apply for:

7:30 PM on 2004 September 9
6:30 PM on 2004 September 24
5:30 PM on 2004 October 9

Our tour of the evening sky starts with the most recognisable of southern constellations, the Southern Cross, which is lying on its side about 15° above the SSW horizon. Nestled just to the left (south) of Beta Crucis is the Jewel Box cluster, an *open cluster* just a few million years old. It was so named because of the varying colours of its stars – this A-shaped cluster features a prominent red giant star near the middle. A little further left is the *dark nebula* known as the Coal Sack, which forms the head of a giant emu described in Aboriginal mythology.

About 15° above (east of) Beta Crucis is Rigel Kentaurus (commonly known as Alpha Centauri). This star is our nearest neighbour at just 4.2 *light years* distant and is a fine *double star* (it is actually a triple star but the third star is very dim at magnitude 11, compared with magnitudes –0.0 and +1.3 for the two bright stars). The two stars orbit each other every 80 years and are separated by between 10 and 40 AU. Our Solar System from the Sun to Pluto would fit between them at their maximum separation.

If we form an equilateral triangle using Alpha Crucis and Alpha Centauri, with the third apex to the right (north), we mark the location of Omega Centauri, arguably the best *globular cluster* in the sky, and home to millions of suns. At around 17 000 light years away it is one of the closest globular clusters. The distance between individual stars averages around one-tenth of a light year, or about 100 times the width of our Solar System.

Returning to Alpha Crucis, if we swing left by about 60°, crossing the south celestial pole, we find the 0.5 magnitude star Achenar, which is the brightest star in the constellation Eridanus the River. Backtracking about one quarter of that distance and then moving upward (west) about 6°, we encounter the Small Magellanic Cloud (SMC), a fuzzy blob of light. The SMC is a small irregular galaxy around 200 000 light years away. Of particular interest is the globular cluster 47 Tucanae, about 3° above (west of) the SMC. This cluster is the second largest after Omega Centauri and probably contains around 500 000 suns.

Swinging our gaze to the western sky, we find the constellation Scorpius at an altitude of about 65°. This constellation is one of few that actually resembles the animal after which it is named. The red supergiant star Antares (which means 'rival to Mars'), so named because of its red colour, marks the scorpion's heart. Directly overhead, about 10° above (east of) Scorpius is Sagittarius the Archer, commonly known as the 'tea pot'.

The region between Scorpius and Saggitarius marks the centre of the Milky Way galaxy and is very rich in nebulas and clusters. Millions of stars are also located in this zone, but clouds of interstallar dust obscure most of them from our view. The Milky Way has the same proportion as two dinner plates placed face-to-face, and has a radius of about 100 000 light years. It contains about 200 billion stars. Our own solar system is situated about two-thirds out from the centre, on one spiral arm called the Orion Arm. Tonight, the Milky Way extends from the north-northeast, running overhead to the south-southwest.

Morning sky

These descriptions apply for:

4:30 AM on 2004 September 10
3:30 AM on 2004 September 25

During mid-September early mornings, the Southern Cross lies very low in the SSE, having risen around 90 minutes beforehand. Extending the same line from Alpha Crucis to Achenar and backtracking as before, but this time moving upward and left (north-east) about 15°, we encounter the Large Magellanic Cloud (LMC). Lying about 160 000 light years away, it is the second closest galaxy to our own (the closest is a dwarf galaxy in Sagittarius). Near the northern end of the LMC is the Tarantula Nebula, which is also the LMC's brightest object. It is the largest known *diffuse nebula* and is an area of star formation, and like its namesake it exhibits an intricate spider-like structure.

Turning our attention to the north we see the constellation Taurus the Bull at an altitude of about 45°. The first magnitude orange giant star Adebaran marks the bull's eye. If placed in the position of our own Sun, it would occupy most of the area inside Earth's orbit. About 2° left (west) we see the inverted V-shape of the Hyades cluster. Moving left and downwards (northwest) about 12° we encounter the Pleiades, a cluster of young, hot, blue stars and the most famous cluster in the sky. This cluster is also known as the Seven Sisters, although with the unaided eye most people can see only six. In reality it contains about 500 mostly faint stars.

About 23° above and right (southeast) of Aldebran lies the centre of Orion the Hunter. Defined by Northern Hemisphere observers, we see Orion upside down (as we do with nearly all equatorial or northern constellations), but it does not take much imagination to picture his raised club and shield, and his belt with his sword hanging below. The central star of Orion's sword is actually the Orion Nebula. This swirling cloud of gas is the home of several young, hot blue-white stars and is an area of continuing star formation. Although photographs reveal an intense red colour, the colour is too faint to be seen with the eye and the nebula is usually perceived as a grey or green colour through a telescope. Legend records that Orion died after being stung by a scorpion and that the two were turned into constellations on opposite sides of the sky. Orion sets as Scorpius rises, and as a result Orion spends eternity fleeing the scorpion. Continuing a further 23° southeast of the Orion Nebula we encounter Sirius, the Dog Star, which is the brightest star in the sky at magnitude –1.4. Only the sun, moon, and bright planets are brighter.

Low in the east, at about 15° altitude, is Saturn, shining at magnitude 0.2. With a diameter of 121 000 km this gas giant is the second largest planet in our Solar System (after Jupiter). It orbits the Sun at a distance of about 9.5 AU and takes almost 30 Earth years to complete one orbit. Despite the fact that it is over nine times the diameter of Earth, it completes a single rotation in just over 10 hours, and as a result of this rapid rotation, it is notably oblate – its equatorial diameter is about 10% greater than its polar diameter.

Saturn's most striking feature is its rings, which span a diameter of about 250 000 km. The ring system would fit neatly between Earth and the Moon, but despite their huge diameter they are only about 1 km thick. Although they appear continuous, they are composed of innumerable objects, mostly ice, all independently orbiting the planet. Because of the tilt of Saturn's and Earth's orbits, we periodically see the rings edge-on, when they become invisible to earthbound observers.

About 6° below and to the left (north) of Saturn is the thin crescent Moon. The Moon orbits Earth at a distance of about 385 000 km, taking about one month to complete an orbit. It is about 3 500 km in diameter, or roughly the same width as Australia, and is Earth's only natural satellite. A view through even a modest telescope will reveal many hundreds of impact craters ranging from simple craters through to complex multi-ring basins. The dark areas, known as **maria** (oceans) are caused by the outflow of lava, possibly resulting from a very large impact event.

About 9° below and to the right (east) of Saturn is Venus, shining brightly at magnitude –4.2. Venus's orbit lies inside that of Earth, and consequently shows phases in much the same way as the moon. Galileo's telescopic observation of this phenomenon in 1610 was instrumental in disproving the Ptolemaic model of the Solar System, which required all planets to orbit the Earth. Had this been the case, Venus could not have shown the thin crescent phases observed by Galileo.

Venus has a very thick atmosphere, which causes it to reflect a large proportion of sunlight and accounts for its visual brightness. However, it also hinders our observation of the surface, which can only be imaged using radar waves. The thick atmosphere also causes a 'runaway greenhouse' effect, resulting in very high surface temperatures of around 460° C.

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Glossary

TERM DESCRIPTION

Ablation: Melting of the outer layers of a piece of space debris during its passage through the Earth's atmosphere (see also *disintegration*).

Acid: Igneous rocks that have a high content of quartz or silica.

Amorphous: Having no regular crystal shape.

Andesite: A dark-coloured volcanic rock, common in volcanoes of the Andes.

Anticline: A fold in a rock layer in which the hinge (the area of tightest curvature) points upward and the limbs extend downward (see also *syncline*). Such a fold would take the shape of an inverted 'U'.

Archaean: A defined period of geological time. It is applied to rocks that are older than 2500 Ma, and extends back to the time of formation of the Earth at about 4560 Ma.

Arcuate: Forming or resembling an arch.

Astronomical Unit (AU): The average distance between the Earth and the Sun; equal to 150 million km.

Basalt: A dark-coloured volcanic rock, typified by Hawaiian volcanic activity.

Breccia: Rock, either cemented or of loose fragments, consisting of broken and angular fragments of older rocks. Formed by mechanical breaking of the earlier rock. Can be either present within the older rock, such as forming a cross-cutting vein, or as a sediment such as where the broken fragments have accumulated at the base of a cliff

Centripetal: Tending to move towards a centre. In the case of drainage patterns, a series of channels that feed towards a central depression.

Chalcedony: A cryptocrystalline, translucent variety of quartz, usually a whitish colour, and an almost wax-like lustre

Craton: A term used to describe a major geological unit of rocks that has been stable for prolonged geological period. These now form the oldest cores of continental plates around which younger rocks have been added through the process of "continental accretion".

Dark nebula: A cloud of dust in interstellar space, made visible because it obscures the light of luminous objects behind it.

Diffuse nebula: A cloud of gas, mostly hydrogen, in interstellar space. Such gaseous nebulae can be divided into emission nebulae and reflection nebulae. Emission nebulae give off their own light, much like a neon sign, whereas reflection nebulae reflect the light from a nearby star, much like fog in car headlights.

Disintegration: Break-up of a piece of space debris during its passage through the Earth's atmosphere (see also *ablation*).

Double star: Two stars seen very close to one another. Optical doubles are caused by a chance alignment of two widely separated stars, whereas true doubles comprise a pair of stars locked together by their mutual gravitational attraction. To the unaided eye most doubles appear as a single star, and can only be resolved into their components using binoculars or a telescope.

Duricrust: A hard, resistant layer that is a component of deep-weathering profiles. In the southwest part of the State they form as concentrations of ironstone or ferricrete, but concentrations of quartz as silcrete occur inland. Being resistant and chemically stable, they form the cappings on breakaways and hilltops.

Dyke: A sheet-like body of rock (usually from a molten origin) that intrudes, below the Earth's surface, into the host rock, cutting across any existing bedding or structural planes (see also *sill*).

Earthquake: A series of shock waves generated from a point within the Earth's crust (see also *fault*). Many thousands of earthquakes occur each year, but very few are felt by humans.

Erosion: Wearing away of the land surface by the mechanical action of transported debris (see also *weathering*).

Fault: A fracture in rock along which there has been observable displacement.

Feldspar: A group of hard, crystalline, rock forming aluminosilicate minerals containing varying amounts of potassium, calcium, sodium, and barium. Together with quartz and biotite they form a major constituent of granite. They are usually white, off-white, pink, or greenish in colour.

Felsic: A term used to describe igneous and *metamorphic rocks* that are dominated by feldspar and quartz, and hence are light-coloured. They include granites of various types.

Fluvial: Of or relating to a river.

Galaxy: A collection of billions of stars, nebulae, and interstellar dust, usually in spiral or elliptical shapes (although some may form irregular shapes). The universe contains many billions of galaxies.

Globular cluster: A grouping of stars numbering in the hundreds of thousands or millions. Nearby globular clusters orbit the Milky Way galaxy, whereas distant ones have been observed in neighbouring galaxies. The stars contained within them are typically many billions of years old.

Gneiss: A *metamorphic rock*, derived by "cooking up an older rock in its own juices". They are distinctly banded on a centimetre-scale, with adjacent bands having different minerals, commonly contrasting light and dark-shaded. The banding may be straight, or can be folded and contorted through later earth-movements.

Granite: To geologists, the rock *granite* has a specific chemical and mineral composition. However, to the layman, granite can be applied to a large range of rocks that geologists have a variety of names for. The term is used in a general sense in this Guide. Granite originates by melting of older rocks deep (from 10 km to 60 km or more) below the surface. Following the melting, the mass of molten rock, or magma, gradually migrates upwards, eventually freezing a forming the granite in large masses, referred to a plutons, in the cooler parts of the crust. These may be connected to volcanoes at the surface.

Granite consists mostly or three minerals, quartz, feldspar and mica. The feldspar actually consists of a range of different minerals, ranging in colour from cream to pink or red, and as the proportion of different feldspar minerals change, they vary the colour of the granite.

Granitic gneiss: *Gneiss* that is pale in colour and is probably derived from metamorphism of an earlier granite.

Granophyre: A volcanic rock, similar in chemical composition to a granite, but consisting of scattered larger crystals of feldspar in a fine-grained matrix.

Greenstone: Zones or areas of rocks that commonly have greenish colours, in contrast to whitestone (an older term that is not used now) or granites. Greenstones consist of a huge diversity of rock, but dominantly are of volcanic or sedimentary origin. They typically now consist of basalt and related rocks or siltstone, shale rare conglomerate and chert, banded-iron-formation and others. These rocks contain most of the gold mined in Western Australia. After formation they were subjected to metamorphism and related changes that have produced new rocks that typically have green minerals (chlorite), and the gold was introduced at the same time.

Heat flow, terrestrial: The rate at which heat is lost from the inner zones of the Earth to the atmosphere.

Kinetic energy: The energy of a moving object, equal to the amount of work required to bring it to rest. It varies in direct proportion to the object's mass, and in proportion to the square of its velocity.

Komatiite: An unusual volcanic lava. They have a very high proportion of magnesium in their composition, and melt at temperatures approaching 1500° C, in comparison with other lavas that melt in the range of 800° C to 1200° C. They were produced during Archaean times when the Earth was younger and much hotter than now. Because the Earth has cooled as it has aged, it is thought that it is now too cool to melt rocks of this compositions and bring them to the surface.

Kuiper Belt: A disc-shaped zone of the Solar System, just outside the orbit of Pluto, containing large numbers of icy objects, which, if perturbed, may fall towards the sun and be observed as comets (see also *Oort Cloud*).

Lag deposit: The residual accumulation of coarse, usually hard, fragments that accumulate at the ground surface. They have been left as a residue after the physical and chemical breakdown of the upper horizons of the regolith and the removal of finer materials in solution or by sheetwash or wind. (From Anand, R. R., & Payne, M., 2002. Regolith geology of the Yilgarn Craton, Western Australia. *AJES*, **49**, pp3 – 162.)

Light Year: The distance travelled by light in one year; equal to 9.5 trillion km.

Lunette: A dune beside a lake, formed from sand-sized material blown off the dry lakebed. Many lunettes in Australia are of gypsum, or clay (blown as sand-sized pellets) as well as normal quartz sand.

Ma: Mega-annum, a unit of geological time. It is a million years.

Mafic: Used to describe igneous or *metamorphic rocks* that are dark caused by the presence of minerals containing high proportions of iron, magnesium and calcium. Mafic igneous rocks include basalt, dolerite and gabbro. They contrast to *felsic* rocks

Matrix: The outer material of a rock comprising larger grains embedded in a material consisting of smaller ones.

Mesosiderite: A category of Stony-Iron meteorites consisting of mixed nickel-iron alloy and rock (basalt). They are thought to have formed through complex histories of catastrophic collision, melting and reformation.

Metamorphic rock: A rock consisting of crystals that were formed from older rocks by being taken to great depth in the crust (from 5 km to many tens of km) by earth movements. At these depths, the original minerals become reconstituted into new minerals that grow as crystals at the extremely high temperatures (from 100° C to over 800° C) and pressures (from many times atmospheric to millions of atmospheres) at depths ranging from a few to over 30 km.

Metasomatism: The process of replacing one suite of minerals in a rock by another, usually understood to be through the movement of pore-water that adds some chemical elements in removing others.

Commonly occurs at elevated temperatures and pressures, and may be considered as accompanying metamorphic processes.

Meteor: A bright streak of light caused by a piece of space debris burning up as it enters the Earth's atmosphere at high speed (see also *meteorite*).

Meteor shower: An increased number of *meteors*, perhaps up to 50 per hour, which appear to radiate from a single point of the sky, caused by the Earth's passage through the debris trail left by a passing comet.

Meteor storm: An exceptionally large number of meteors, up to 20 per second (see also *meteor shower*), associated with particularly dense debris zones left by passing comets.

Meteorite: A piece of space debris that reaches the Earth's surface (see also *meteor*).

Oort Cloud: A spherical zone of the Solar System, up to one light year (~60 000 *AU*) from the Sun, containing billions of icy objects. These objects may be perturbed by the Solar System's passage through the Milky Way galaxy or by the gravitational effect of a passing star, in which event they may fall towards the Sun and be observed as comets (see also *Kuiper Belt*). Named after Dutch astronomer Jan Oort.

Open cluster: A grouping of stars numbering in the tens to hundreds, locked together by mutual gravitational attraction. Such clusters are typically found within our own Milky Way galaxy and comprise young stars, perhaps as young as a few million years.

Orogen: A geological region resulting from a period of mountain building.

Palaeodrainage: Literally 'ancient drainage'. The climate of Western Australia was much wetter during the Cretaceous to middle Miocene periods, resulting in the formation of large river systems. As the climate became more arid, these systems gradually dried up until they became the strings of salt lakes visible today. When viewed in satellite imagery, the lakes can be seen to define the path of the original rivers. In some cases, more recent sediments have obscured the palaeodrainage channels, creating buried palaeodrainage.

Pegmatite: A very coarse grained igneous rock (i.e. from a molten source) with crystals greater than 3 cm in size. In rare cases the crystals can reach up to 1 m. Pegmatites usually have a similar composition to granite, and may also contain rare minerals such as tourmaline, topaz, and fluorite.

Perturbation: A disturbance caused to the regular path of an orbiting object, produced by an external force. Typically caused by a close encounter with another, more massive, object.

Plate tectonics: Relative movement of large regions of the Earth's crust (called plates); responsible for the formation of major mountain ranges, earthquakes, and mid-ocean ridges.

Pluton: A large mass of granite, ranging from the order of several kilometres across to well over 100 km. They originated as a large volume of molten rock that was slowly being buoyed upwards towards the Earths crust, freezing as they enter cooler zones.

Proto-planet: The stage in a planet's formation at which it is nearly full sized.

Quartz: A hard, rock forming crystalline mineral, consisting of pure silica (silicon dioxide, SiO_2). Present in most rocks and usually colourless or transparent.

Regolith: The soils, weathered bedrock, alluvium and other similar materials that cover rocks.

Rhyolite: A volcanic rock that typically contains small crystals, formed before the melt was extruded.

Rock mechanics: The mechanical properties of rocks, particularly their strength, elasticity, porosity, permeability, and any faults, joints or defects contained within them. These properties collectively determine the stability (and therefore likelihood of collapsing) of any slopes excavated within them.

Shatter cones: Distinctive rocks or fragments of rock with conical shape and with strong striations, looking like horses-tail feathering, on the outer cones. They are caused when a very high-pressure shock wave passing through the original rock, meets a slight change in the rock properties and produces a refracted wave that travels down with the original wave front. The pressures needed to produce these are the order of over 5 gigapascals or some 50 000 times normal atmospheric pressure.

Sill: A sheet-like body of rock (usually from a molten origin) that that intrudes, below the Earth's surface, parallel to any existing bedding or structural planes of the host rock (see also *dyke*).

Sporadic meteors: Random *meteors* (typically around five per hour) visible during a dark (moonless) night at any given day of the year. The rate increases after midnight, as the observer's location tends to 'sweep up' particles of space debris (see also *meteor shower*, *meteor storm*).

Striated: Small grooves in a rock surface.

Supernova: The explosion of a dying star, becoming extremely luminous in the process. Much of the star's mass is blown off during such an event.

Syncline: A fold in a rock layer in which the hinge (the area of tightest curvature) points downward and the limbs extend upward (see also *anticline*). Such a fold would take the shape of a 'U'.

Tectonic: Relating to a structural or mountain building event.

Terrestrial: Of or pertaining to planet Earth.

Transient: Temporary. In the case of impact craters, the crater that exists immediately before commencement of the modification stage, at which time the crater is back-filled with ejected material.

Unconformity: The surface between two rock units that represents a time break. For example when an old land surface sinks below the sea level and sediments are then deposited, the top of the old soil surface (and rocks underlying it) is much older than the new sediments, and forms an unconformity surface. These are very important geological features that reveal much about time relationships between rock units.

Volcanism: The activity of volcanoes, which are vents or fissures in the Earth's crust through which magma (molten rock), hot gasses, and other fluids escape.

Weathering: The process by which rocks are broken down, either mechanically or chemically, without being transported to a different location (see also *erosion*).

Widmastätten: A structure found in iron meteorites. It consists of trellis-or lattice shaped network of interlocking crystals of three different nickel-iron minerals, kamacite, taenite and tetrataeinite. They are revealed when iron-nearing meteorites are polished and etched with acid. The crystals form as the nickel-iron alloy cools slowly, allowing migration of the nickel atoms within the taenite (alloy) to form kamacite as plates that are aligned by the existing crystal structure in the taenite. When the cooling is very slow, crystals of tetrataeinite form along the boundary between the two earlier-formed minerals. The presence of this structure in with crystals of the size seen in meteorites (centimetre-scale) shows that the alloy cooled at extremely slow rates. These rates are the order of a few tens of degrees per million years, probably in the core of large early-formed planets or asteroids body that were then disrupted.

APPENDIX 1

List of Western Australian and Australian Craters and Impact Structures

Western Australian Craters

CRATER NAME	LATITUDE	LONGITUDE	DIAMETER (km)	Age (Ma)*	EXPOSED	WITH METE-ORITE
Connolly Basin	S 23° 32'	E 124° 45'	9	< 60	YES	N
Dalgaranga	S 27° 38'	E 117° 17'	0.024	~ 0.003	YES	YES
Goat Paddock	S 18° 20'	E 126° 40'	5.1	< 50	YES	NO
Piccaninny	S 17° 32'	E 128° 25'	7	< 360	YES	NO
Shoemaker	S 25° 52'	E 120° 53'	30	1300 - 568	YES	NO
Spider	S 16° 44'	E 126° 05'	13	> 700	YES	NO
Veevers	S 22° 58'	E 125° 22'	0.08	< 0.004	YES	YES
Wolfe Creek	S 19° 10'	E 127° 48'	0.875	< 0.3	YES	YES
Woodleigh	S 26° 03'	E 114° 39'	40	364 ± 8	NO	NO
Yallalie	S 30° 27′	E 115° 46′	12	Late Creta-ceous	NO	NO
Yarrabubba	S 27° 10'	E 118° 50'	30	~ 2000	YES	NO

Australian Craters

CRATER NAME	STATE	LATITUDE	LONGITUDE	DIAMETER (km)	Age (Ma)*	EXPOSED	WITH METE-ORITE
Acraman	South Australia	S 32° 01'	E 135° 27'	90	~ 590	YES	NO
Boxhole	Northern Territory	S 22° 36' 50′	E 135° 11' 41″	0.17	.0540 ± 0.0015	YES	YES
Crawford	South Australia	S 34° 43'	E 139° 02'	8.5	> 35	YES	NO
Flaxman	South Australia	S 34° 37'	E 139° 4'	10	> 35	YES	NO
Foelsche	Northern Territory	S 16° 40'	E 136° 47'	6	> 545	NO	NO
Gosses Bluff	Northern Territory	S 23° 49'	E 132° 18'	22	142.5 ± 0.8	YES	NO
Goyder	Northern Territory	S 13° 28.5'	E 135° 02'	3	< 1400	YES	NO
Henbury	Northern Territory	S 24° 34'	E 133° 08'	0.157	.0042 ± 0.0019	YES	YES
Lawn Hill	Queensland	S 18° 40'	E 138° 39'	18	> 515	YES	NO
Liverpool	Northern Territory	S 12° 24'	E 134° 03'	1.6	150 ± 70	YES	NO
Mount Toondina	South Australia	S 27° 57'	E 135° 22'	4	< 110	YES	NO
Strangways	Northern Territory	S 15° 12'	E 133° 35'	25	646 ± 42	YES	NO

Information from University of New Brunswick database of impact sites and amended by authors, including data from Bevan and deLaeter (2002), Haines (1996), Wells *et al* (1970), Freeman (1986), Milton *et al* (1986), Bevan (1996), Macdonald & Mitchell (2004), Glikson (1996), and Pirajno (2002)

APPENDIX 2

Timing of Geological Events Relative to a "Geological Year" *

GEOLOGICAL TIME UNIT				MILLIONS OF YEARS AGO	EVENT	DATE/TIME IN A "GEOLOGICAL YEAR"
EON	ERA	PERIOD	EPOCH			
Archaean Eon				4560	Condensation of planets and the sun from original nebula, beginning of Earth	1 Jan
				4410	Oldest minerals known on Earth, zircon grains from Jack Hills in Murchison region	14 Jan
				3900	Inferred origin of life (first cells)	23 Feb
				3800	Oldest dated rocks in Australia, at Mt Narryer in Murchison	2 Mar
				3600	Fossil blue-green algae and stromatolites (prokaryots)	18 Mar
				3450	Oldest fossils, stromatolites in Pilbara, including bacteria at Chinamans Creek near Marble Bar	30 Mar
				3000	Windy Harbour gneiss and granulite	5 May
				2600	Age of widespread granite intrusions in Yilgarn and formation of Yilgarn gold	6 Jun
Proterozoic Eon	Palaeoproterozoic Era			2500	Age of much iron ore in Pilbara	14 Jun
				2100	First fossil evidence of single-celled life with a cell nucleus (eukaryots)	16 Jul
				2000	Possible age of precursor rocks in Albany-Fraser Orogen	24 Jul
	Mesoproterozoic Era			1800		9 Aug
				1500	First multicelled organisms (seaweed and algae)	2 Sep
	Neoproterozoic Era			1200		26 Sep
				1200	Age of Albany-Fraser Orogen	26 Sep
				730	First global ice age	3 Nov
				670	Oldest marine worms and jellyfish	8 Nov
		Ediacaran Period		600		13 Nov
				600	Edicarian fossils, start of multicellular life	13 Nov
Phanerozoic Eon	Palaeozoic Era	Cambrian Period		542	Start of rapid evolution and radiation of many forms of life	18 Nov
				513	Burgess Shale organisms (Canada): first animals with a primitive backbone	20 Nov
		Ordovician Period		488.3		22 Nov
				505	First fish	21 Nov
				470	First fossil evidence of land plants	24 Nov
		Silurian Period		443.7		26 Nov

GEOLOGICAL TIME UNIT				MILLIONS OF YEARS AGO	EVENT	DATE/TIME IN A "GEOLOGICAL YEAR"
EON	ERA	PERIOD	EPOCH			
				430	First vascular land plants	27 Nov
				414	Oldest lung fish fossils	28 Nov
		Devonian Period		416.0		28 Nov
				408	Oldest fossil evidence of mosses	29 Nov
				385	First insects (beetles), scorpions, and centipedes	1 Dec
				380	First lobe-finned fish	1 Dec
				375	First land animals (amphibians)	1 Dec
				370	First sharks	2 Dec
				365	First seed plants (ferns)	2 Dec
		Carboniferous Period		359.2		3 Dec
				330	First possible reptiles	5 Dec
		Permian Period		299.0		8 Dec
				290	Second global ice age,	8 Dec
				270	Collie coal deposited	10 Dec
	End of Palaeozoic			251	96% of life on Earth perishes	11 Dec
	Mesozoic Era	Triassic Period		251.0	Start of the "Age of Reptiles"	11 Dec
				240	First crocodiles	12 Dec
				228	First dinosaurs: *Eoraptor* and *Saltoposuchus*	13 Dec
				221	First mammals	14 Dec
		Jurassic Period		199.6		16 Dec
				153	First bird, *Archeopteryx*	19 Dec
		Cretaceous Period		145.5		20 Dec
				142.2	Impact of Gosses Bluff comet, central Australia	20 Dec
				133	Age of outflowing of Bunbury Basalt, as India started splitting away from WA	21 Dec
				117	First flowering plants	22 Dec
				77	*Triceratops*	25 Dec
				72	*Tyrannosaurus rex*	26 Dec
	End of Mesozoic			65.5	Asteroid or comet impact at Chixulub in Mexico	26 Dec
	Cenozoic Era	Palaeogene Period	Palaeocene Epoch	65	Start of the "Age of Mammals"	26 Dec
				64	First ancestors of dogs and cats	26 Dec
				60	Grasses become widespread	27 Dec

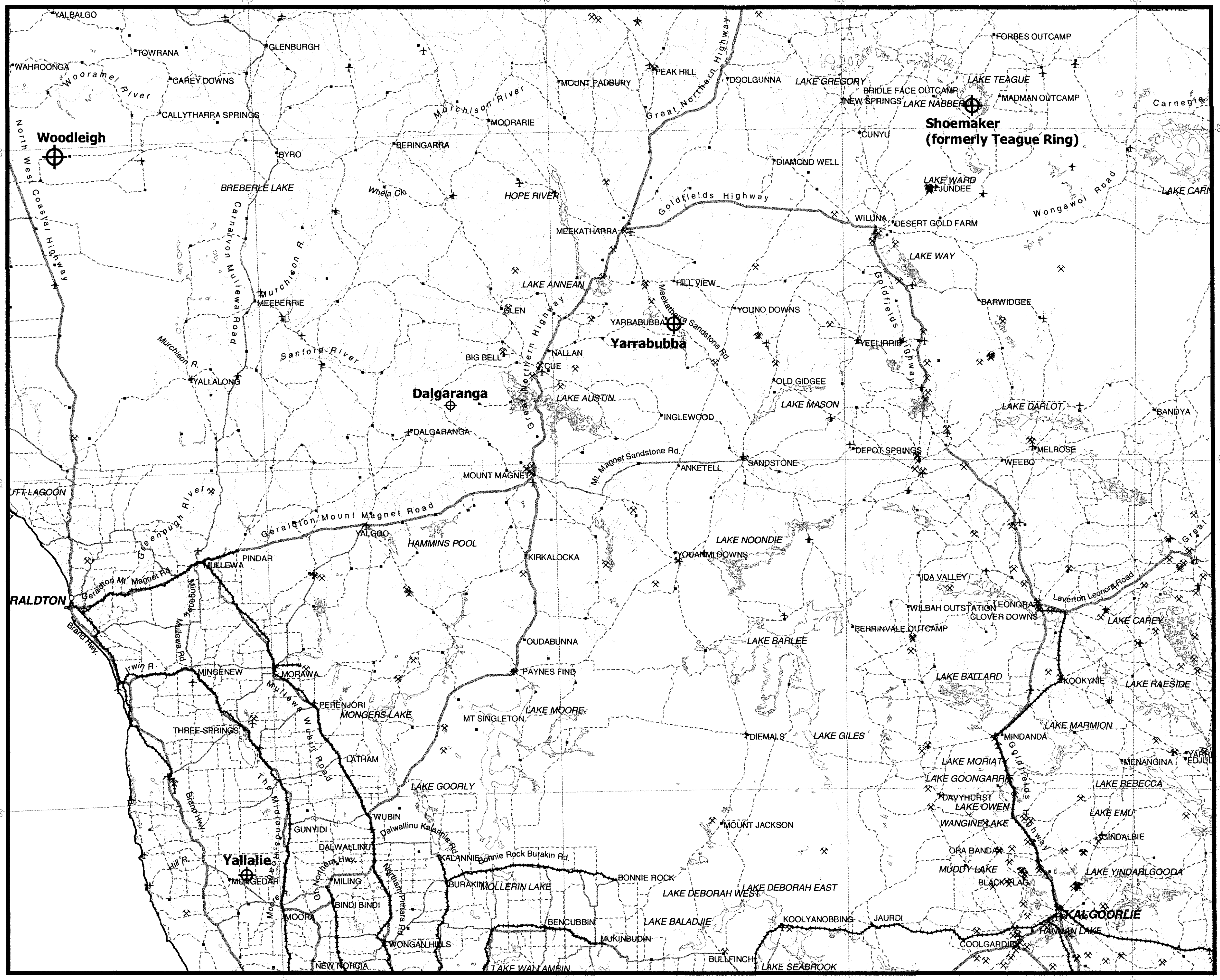
GEOLOGICAL TIME UNIT				MILLIONS OF YEARS AGO	EVENT	DATE/TIME IN A "GEOLOGICAL YEAR"
EON	**ERA**	**PERIOD**	**EPOCH**			
			Eocene Epoch	55.8		27 Dec
				55	Widespread global sea level rise of 200 m, Bremer and Eucla Basins inundated; First horses (*Eohippus*)	27 Dec
				39	First monkeys	28 Dec
			Oligocene Epoch	33.9		29 Dec
				25	Oldest ice at Poles, start of modern ice ages	29 Dec
		Neogene Period	Miocene Epoch	23.0		3:48 on 30 Dec
				20	Formation of Ravensthorpe Ramp, change of drainage along south coast	9:34 on 30 Dec
			Pliocene Epoch	5.3		13:49 on 31 Dec
				5	Oldest human-like ancestors (hominids)	14:23 on 31 Dec
				3.5	Age of youngest laterite in Australia	17:16 on 31 Dec
				2	First of four major ice advances across northern hemisphere - ice ages	20:09 on 31 Dec
			Pleistocene Epoch	1.8		20:32 on 31 Dec
				1	Oldest direct human-ancestor fossil, *Homo habilis.* Time of formation of Veevers Crater	22:04 on 31 Dec
				0.3	Wolfe Creek Meteorite impact	23:25 on 31 Dec
				0.1	First modern man, *Homo sapiens*	23:48 on 31 Dec
				0.06	? First evidence of human activity in Australia	23:53 on 31 Dec
				0.014	End of last ice age maxima	23:58:23 on 31 Dec
				0.011	Start of last rapid global sea-level rise from -130 m	23:58:44 on 31 Dec
			Holocene Epoch	0.01	(10 000 years ago)	23:58:51 on 31 Dec
				0.007	End of last rapid sea-level rise	23:59:12 on 31 Dec
				0.002	Time of Christ and start of modern calendar	23:59:46 on 31 Dec
				AD YEARS		
				1066	Magna Carta signed	23:59:54 on 31 Dec
				1606	First documented visit to Australia	23:59:57 on 31 Dec
				1770	Australia visited by Captain Cook	23:59:58 on 31 Dec
				1829	Western Australia settlement at Perth established	23:59:59 on 31 Dec

** Assuming Solar System formed by start of 1st January and now is midnight at the end of 31st December*

PERTH OBSERVATORY VOLUNTEER GROUP

SHOEMAKER IMPACT STRUCTURE

PLATE 1
REGIONAL MAP



Legend

- ⨯ Mineral Deposits

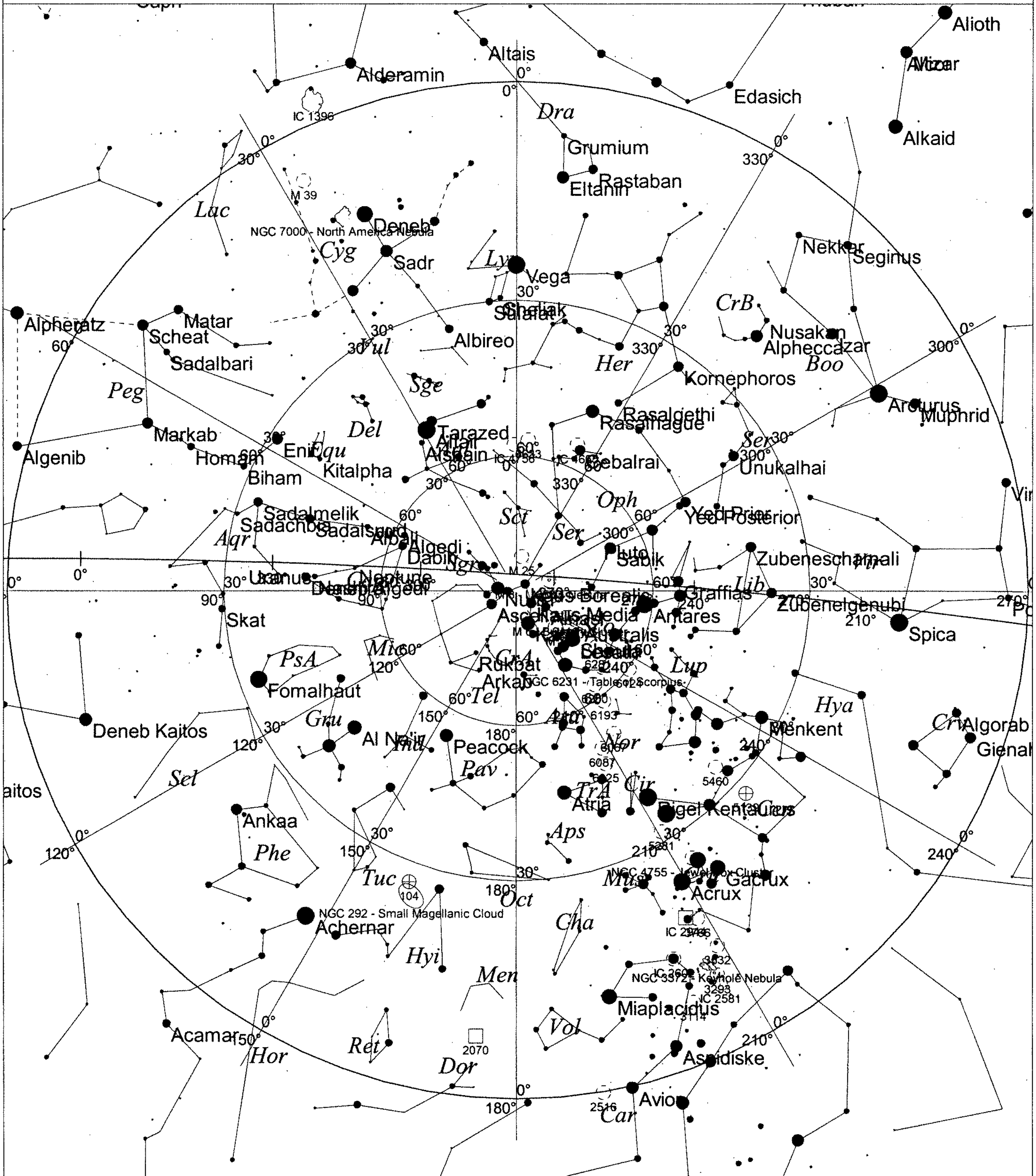
Impact Structures
- 0.024 - 4 km
- 4 - 13
- 13 - 30
- 30 - 55
- 55 - 90 km
- + Landing Grounds

Roads
- Highway
- Primary Route
- Secondary Route
- Other

25 0 25 50 75 Kilometers

Scale: 1 : 2 500 000
Projection: Albers Equal Area
Standard parallels 17°28'30" and 31°30'46"
GDA 94 Datum
FPB AUG04

Shoemaker Impact Structure
Evening Sky -- September 2004

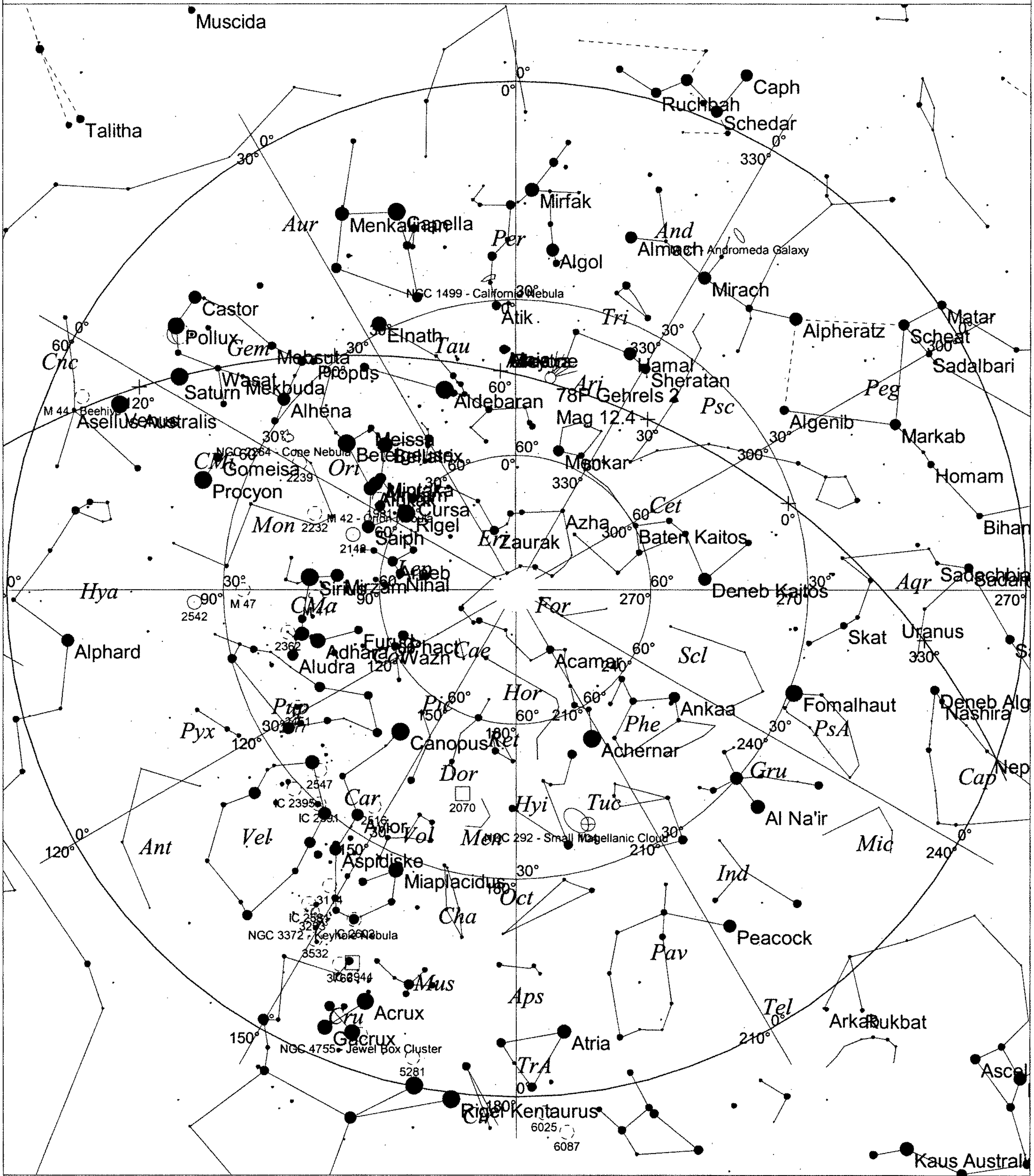


STARS		SYMBOLS			
<1	3.5	Multiple star	Dark nebula	Radio source	
1.5	4	Variable star	Globular cluster	X-ray source	
2	4.5	Comet	Open cluster	Other object	
2.5	>5	Galaxy	Planetary nebula		
3		Bright nebula	Quasar		

Plate 2

Local Time: 19:30:00 9-Sep-2004 UTC: 11:30:00 9-Sep-2004 Sidereal Time: 18:37:24
Location: 27° 0' 0" S 118° 0' 0" E RA: 18h37m24s Dec: -27° 00' Field: 182.0° Julian Day: 2453257.9792

Shoemaker Impact Structure
Morning Sky -- September 2004



STARS		SYMBOLS		
<1	3.5	Multiple star	Dark nebula	Radio source
1.5	4	Variable star	Globular cluster	X-ray source
2	4.5	Comet	Open cluster	Other object
2.5	>5	Galaxy	Planetary nebula	
3		Bright nebula	Quasar	

Plate 3

Local Time: 04:30:00 10-Sep-2004 UTC: 20:30:00 9-Sep-2004 Sidereal Time: 03:38:53

Location: 27° 0' 0" S 118° 0' 0" E RA: 3h38m53s Dec: -27° 00' Field: 182.0° Julian Day: 2453258.3542

6

ːw Observations of Mars from the Odyssey Thermal Emission ıaging System

Christensen (Arizona State University), B.M. Jakosky (University of ˌıorado), H.H. Kieffer (U.S. Geological Survey), M. Malin (Malin ace Science Systems), H. McSween (University of Tennessee), K. Neal- (University of Southern California), J. Bell (Cornell University), vanov (Jet Propulsion Laboratory), M. Lane (PSI), J. Moersch (Uni- ..ity of Tennessee)

The Thermal Infrared Imaging System (THEMIS) instrument has studied ıurface mineralogy, physical properties, and atmosphere of Mars using i-spectral thermal-infrared and visible images in 14 spectral bands from l5 to 15.5 m during the first five months of the Mars Odyssey mapping ssion. The THEMIS objectives are to map mineral units, map the ther- hysical properties of the entire planet, search for thermal anomalies ciated with active sub-surface hydrothermal systems, investigate the operties of the poles, and study atmospheric temperature, aerosols, and ndensates at high (100-m) spatial resolution. The THEMIS multi-spectral ɉes have provided new information on the physical and compositional erties of the martian surface. Initial results include: (1) The individual ..s within layered deposits, for example the terrains of Meridiani Terra, ve significantly different physical properties, indicating either different -·fication/cementation processes or different initial depositional conditions nvironments. (2) Local exposures of surfaces with thermal inertias ap- ching bedrock have been observed, indicating that the rock production e exceeds the rate of burial or erosion and that bedrock is exposed in ıive environments. (3) Crater ejecta show differing degrees of rock pres- tion, providing an additional tool for determining surface modification ; and assessing crater ages. (4) Compositional differences are apparent in ılti-spectral thermal IR images at spatial scales of 100s of meters. (5) ɉional 100-m mapping has revealed the presence of channel systems in ənt crater terrains not detected by Viking and not mapped by the high- lution camera on Mars Global Surveyor. (6) IR imagery has provided antitative physical properties of aeolian surfaces, including dunes, wind eaks, inter-dune surfaces, lags, and mega-ripples, allowing assessment of processes that form these features.

ınding for this research was provided by NASA through the Mars Od- sey Project.

⁻⁻sion 12: Comets: Comae, Tails, Solar Wind əraction
ral Session, 1:30-3:30pm
hairs: A. Cochran and L.M. Woodney, Ballroom

.01

rowband Photometric Results for Comets LINEAR (2000 WM1) ıd Ikeya-Zhang (2002 C1)

˜ʒ. Schleicher (Lowell Obs.), P. V. Birch (Perth Obs.)

ʼe present analysis and results from narrowband photometry of Comets NEAR (2000 WM1) and Ikeya-Zhang (2002 C1) during their recent ap- ritions. We began monthly photometric observations of LINEAR in Au- 2001 (r = 2.7 AU) using the Hall 1.1-m telescope at Lowell Observa- , and these continued until mid-December, when LINEAR became a uthern hemisphere object and observations proceeded from Perth Obser- tory near perihelion (0.6 AU). LINEAR again became available from the ı in March 2002, and was followed outward until July (2.9 AU). Over range of distances, gas production rates varied by more than 150x, but ııowed a canonical water vaporization curve inside of about 2.4 AU, con- ıtent with an active area of about 10 km^2 and a lower limit of the effective eus radius of about 0.9 km. Measurements of Ikeya-Zhang began in ʼuary from Perth (0.9 AU) and continued from Lowell beginning in April .ı AU) and are on-going, with the most recent observations obtained in July (2.1 AU). Gas production r-dependences for I-Z are slightly steeper than a canonical vaporization model, and imply an active area of about 16 km^2, or a minimum effective radius of 1.1 km. Both comets have moderately high gas-to-dust ratios. These and other results for each comet will be presented. This research is supported by NASA.

12.02

The HNC/HCN Ratio in Comets C/2000 WM1 (LINEAR) and C/2002 C1 (Ikeya-Zhang)

W.M. Irvine, D. McGonagle (UMass), P. Bergman (Onsala Space Obs.), T.B. Lowe (JAC), H.E. Matthews (JAC & HIA), A. Nummelin (Chalmers), T.C. Owen (UHawaii)

In cold interstellar clouds HNC has an abundance which can approach or even exceed that of HCN, a gross dis-equilibrium which can be understood in terms of the kinetics of ion-molecule reactions at low temperatures and densities. The discovery of cometary HNC in comet C/1996 B2 (Hyakutake) thus seemed to provide evidence for the survival of interstellar ices in comets. Subsequent data for comet C/1997 O1 (Hale-Bopp) showed, however, a dependence of the HNC/HCN ratio on heliocentric distance that indicated that most HNC in that comet was produced in the cometary coma, rather than being a constituent of the comet's nucleus. Moreover, the initially apparently successful attempts to model HNC production in the coma have been shown to be too simplistic, and more realistic models have thus far failed to produce sufficient HNC to match the observations in comets less active than Hale-Bopp. We have therefore observed both HCN and HNC in 2 recent comets, bringing the number of comets with published measurements of the HNC/HCN abundance ratio to 6. The HNC/HCN ratio in comet C/2002 C1 (Ikeya-Zhang) appears to increase with decreasing heliocentric distance, indicating that the HNC is produced at least in part by processes in the coma. Both comets C/2000 WM1 (LINEAR) and C/2002 C1 (Ikeya-Zhang) exhibit values of the HNC/HCN ratio that appear to be too large (0.10-0.20) to be matched by current models of coma chemistry. Cometary HNC may be a photodissociation product of organic grains or large organic polymers stored in the nucleus.

12.03

SWAN Observations of C/2000 WM1 (LINEAR)

J.T.T Mäkinen (Finnish Meteorological Institute), J.-L. Bertaux, E. Qu émerais (Service d'Aéronomie, France), E. Kyrölä, W. Schmidt (Finnish Meteorological Institute), R. Lallement (Service d'Aéronomie, France)

The SWAN instrument on board the SOHO spacecraft is a scanning Lyman-α imager capable of covering the entire sky on a daily basis. Comets whose extended neutral hydrogen envelope resonantly scatters solar Lyman-α light can be detected from the SWAN full sky maps down to an approximate total visual magnitude of 11.

In addition to the synoptic full sky observations, SWAN conducts specific observations of bright comets with enhanced spatial resolution and photometric sensitivity. The promising comet 2000 WM1 was taken into the observing program from the beginning of November 2001 and was tracked throughout the perihelion. We present the analysis of all SWAN observations of C/2000 WM1 with derived water production rates around the perihelion passage including the January outburst.

The work of J.T.T. Mäkinen is funded by the Academy of Finland. The attendance of J.T.T. Mäkinen to the 34th DPS Meeting is funded by the Vilho, Yrjö, and Kalle Väisälä Fund.

12.04

Spatially-resolved Spectroscopy of C/2002 C1 (Ikeya-Zhang) with HST

H. A. Weaver (JHU/APL), P. D. Feldman (JHU), M. F. A'Hearn (UMD), C. Arpigny (U. Liège), M. R. Combi (U. Michigan), M. C. Festou (Obs. Midi-Pyrénées), G.-P. Tozzi (Arcetri)

The Hubble Space Telescope (HST) was used to observe C/2002 C1 (Ikeya-Zhang) for 9 orbits during 2002 April 20-23 UT when the comet's heliocentric distance was 0.9 AU and the geocentric distance was 0.4 AU. Spectral images taken with the Space Telescope Imaging Spectrograph

TUESDAY