Australian Government

Australian Nuclear Science & Technology Organisation

Australian Replacement Research Reactor Seismic Ups and Downs

14th Pacific Basin Nuclear Conference, Honolulu
21-25 March 2004

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Australia's replacement research reactor

- In Sept 1997, the Australian government agreed to fund ANSTO to construct a 20 MW LEU open pool multi-purpose research reactor to replace the ageing HIFAR reactor.
- The reactor was to:
  - make maximum use of inherently safe systems and minimise radioactive emissions
  - provide for 4 times the irradiation capacity for medical and industrial uses
  - include both thermal and cold neutron beams and guides in a separate guide hall
  - allow for up to 17 state of the art neutron beam instruments
  - be a regional centre of excellence in neutron science

Background to reactor construction

- Environmental impact statement – draft in August 1998 and the final version, after taking into account nearly 1000 public submissions, was lodged in January 1999. Approval was obtained in March 1999.
- Licence to site the reactor based on a detailed safety case. This was granted in September 1999.
- Tender process – prequalification and final evaluation of tenderers.
- Participating in two Senate inquiries into the need for the reactor.
- Licence to construct the reactor, based on the preliminary Safety Analysis Report (PSAR) - obtained in April 2002, including impact of 9/11.
- **5 phases of public submissions, 2 IAEA peer reviews, 2 licences, 2 Senate inquiries and 2 EIS phases took nearly 4 and a half years**

Background to seismic design

- State of the art probabilistic seismic hazard analysis carried out to determine seismic design basis. This also provided new information on the seismology of SE Australia. Figure 3.1.
- The PSHA gave a pga of 0.37g at 10,000 year return period and a maximum spectral acceleration of 0.67g at t=0.1s
- Relatively high pga value because of lack of data on large earthquakes, small data record (e.g. only 30 years digitised data) and lack of attenuation relation for SE Australia
- The chosen seismic design spectrum encompassed all previous seismic estimates and was a demanding criterion.

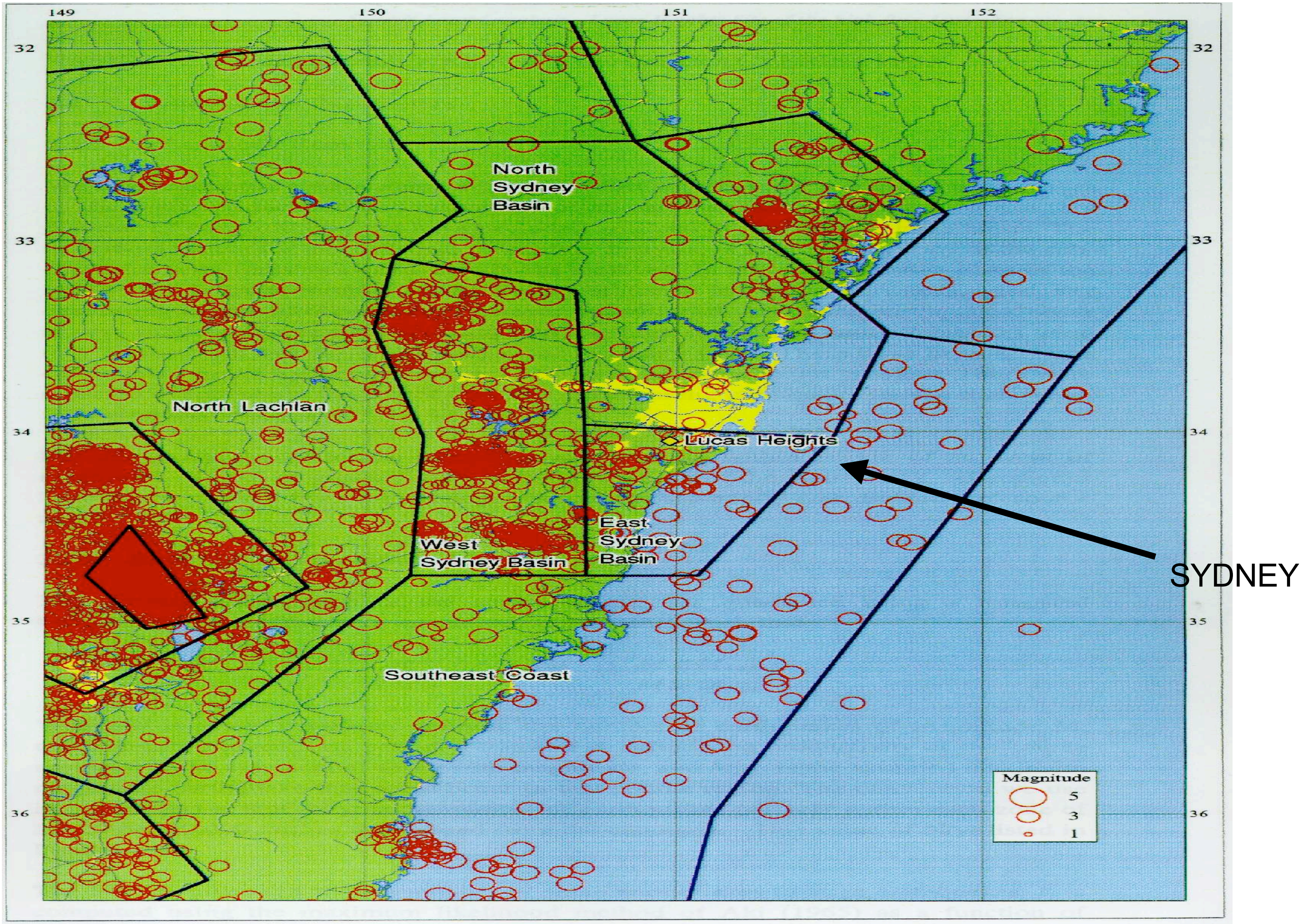

149
150
151
152
32
33
34
35
36
North Sydney Basin
North Lachlan
Lucas Heights
West Sydney Basin
East Sydney Basin
Southeast Coast
Magnitude
5
3
1
SYDNEY

Fig. 3.1

Background to seismic field studies

- Numerous geophysical, geotechnical and seismological studies were done for the LH site and reported in the EIS and PSAR. The design of the RRR took these into account.
- Following submission of the licence application and review by the IAEA, ANSTO carried out a near field and a site seismic study.
- The near field study was given to the regulator in January 2002 - it did not show any evidence of active faults in the region within 5 km of the site.

Party time

Site excavations

- Following the issue of a construction licence in April 2002, ANSTO was able to commission the site excavation study.
- This discovered 2 fault strands in the reactor building excavations that necessitated further study.
- These studies involved understanding the type and characteristics of the faulting, placing the faulting in a regional context and dating the last movement on the fault.

Lucas Heights Site Map

Analysis of geology and seismology of the site

- There are no generally accepted methodologies for performing geological and seismological site assessments for a research reactor.
- ANSTO used the regulatory guidelines for nuclear power plants, which are conservative for this type of facility.
- The geological assessment submission follows the IAEA guidelines for NPPs and comparison was also made with the USNRC criteria, also for NPPs.

Assessment Approach

IAEA Guideline Section 3 of SS 50 SG S1 (1991)	Section of this analysis
Regional study containing all the information that potentially affects the seismic hazard at the site (typically out to 150 km).	Seismic report (1999), Chapter 3 of the PSAR
Near re gional study to define the seismotectonic characteristics of the near region (out to 25 km).	Regional study
Site vicinity study out to 5 km to understand the potential for permanent ground deformation, including surface faulting.	Near site study
Site are a study, up to 1 km ^{2} to add detailed knowledge on the potential for permanent displacement.	See section on mapping of the site and the excavations

Regional Geology

- There is extensive data on the geology and seismology of the Sydney Basin. The basin extends northwards from Bateman's Bay to approximately 200 km north-northwest of Botany Bay.
- Rocks of the Sydney Basin have been weakly deformed by a series of tectonic events. Typical fault displacements are less than 15 m but occasional displacements of up to 100 m have been reported
- Widespread faulting has been observed throughout the region and mapped extensively in the coal mines and as part of tunnel data for new roads and water/sewage transport channels. Figure 4.1.

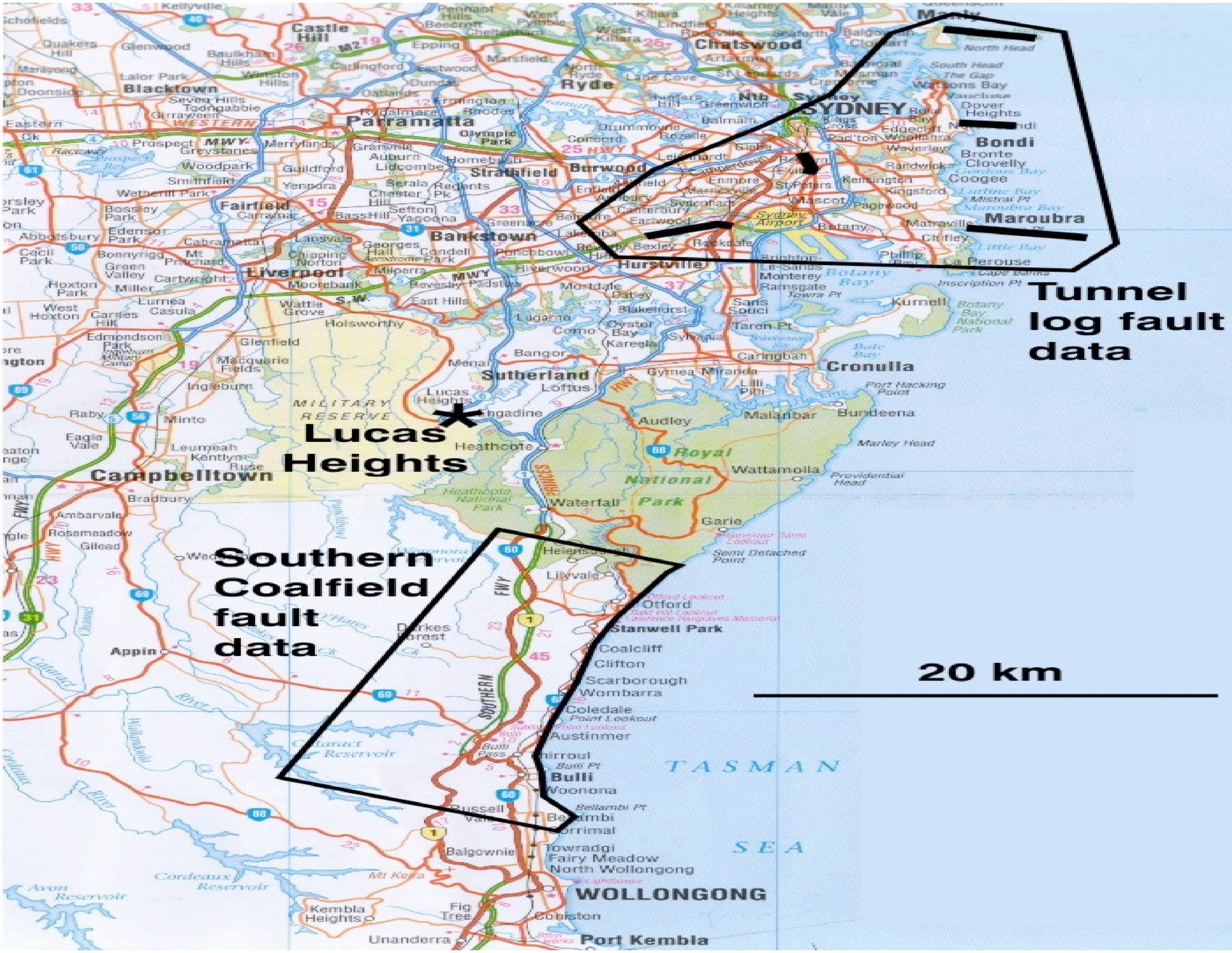
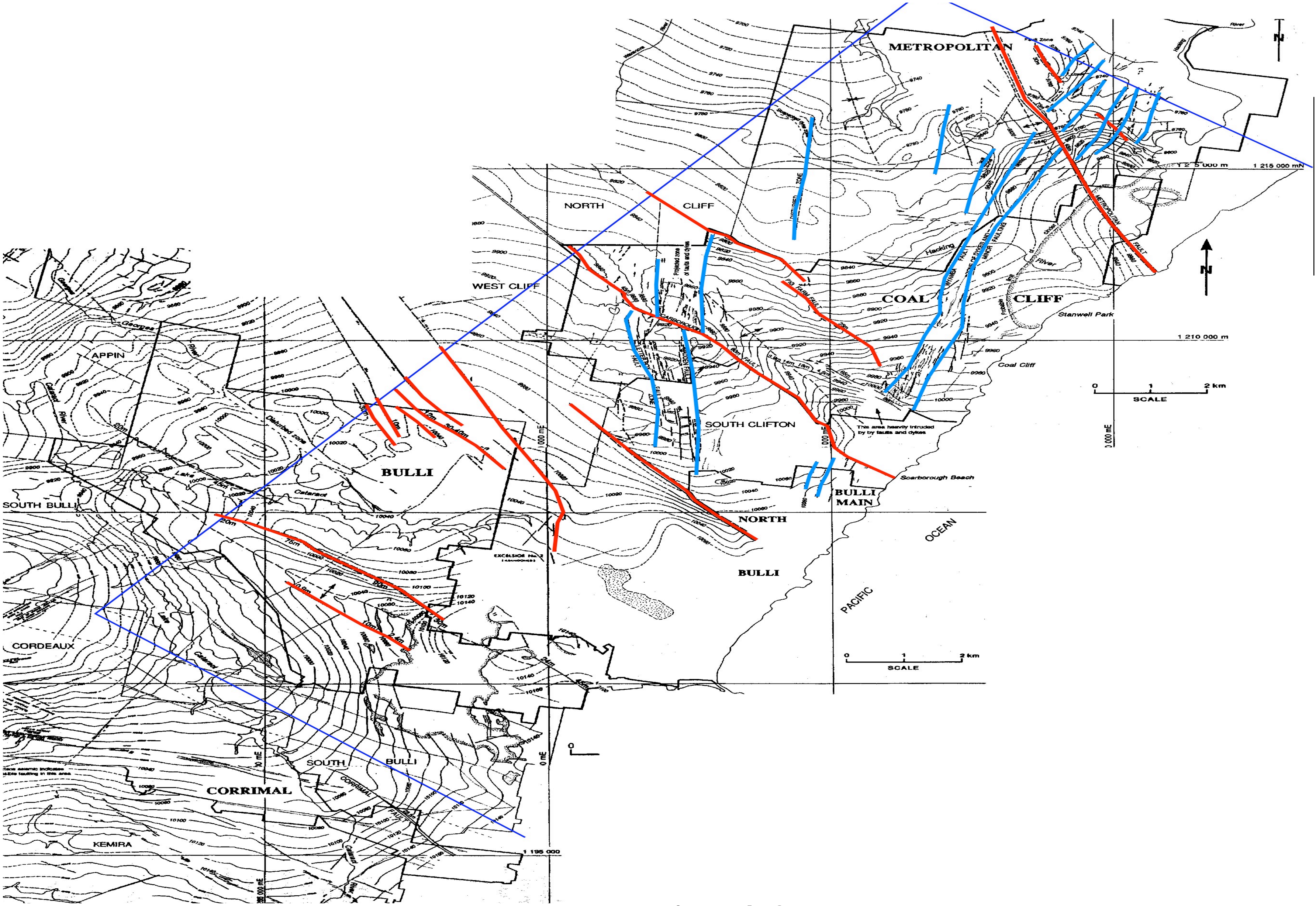

Tunnel
log fault
data
Lucas
Heights
Southern
Coalfield
fault
data
20 km
SYDNEY
WOLLONGONG
TASMAN
SEA

Fig. 4.1

Regional Geology

- The two main fault directions in the region are northwest and north-northeast. In displacement terms, the northwest striking faults are the dominant set. The fault strands on the RRR site belong to the north-northeast set. Figure 4.2.
- The Lapstone Structural Complex is a prominent tectonic and physiographic feature of the Sydney Basin. It consists of a number of related folds and faults, tending generally north-south, coincident with the eastern margin of the Blue Mountains. It is located about 60km west of Sydney and 35km west of Lucas Heights. Maximum displacement on any one fault plane is 100 metres.



METROPOLITAN
NORTH
CLIFF
WEST CLIFF
COAL
CLIFF
APPIN
BULLI
SOUTH BULLI
SOUTH CLIFTON
BULLI MAIN
NORTH
BULLI
CORDEAUX
SOUTH
BULLI
CORRIMAL
KEMIRA
OCEAN
PACIFIC
Stanwell Park
Coal Cliff
Scarborough Beach
SCALE

Fig. 4.2

Regional Geology

- Extensive investigations indicate that Lucas Heights is located in a zone dominated by low amplitude folding and normal faults, different to the LSC.
- Normal faults have been seen, on average, every 140 metres in the tunnel data and apparent reverse faults every 1-3 km. These sets of faults have generally small displacements (less than 15 metres).
- The geology and fault characteristics of the RRR site are consistent with the general pattern of extensive faulting that persists in the local region, a region of low tectonic activity.

Results of the Near Field Study

- The near field study presents the results of a desk study and field reconnaissance of fault and lineament data in an area within 5 km of the RRR site
- The field investigations of a number of identified areas did not reveal the presence of faults where surficial materials were preserved
- Three minor normal faults in weathered rock, with vertical displacements of less than approximately 0.3m were observed at three locations.
- There is no evidence that these faults are active and pose an earthquake hazard for the RRR site.

Mapping of site and excavations

- Mapping of the site excavations (Part 2 of study) began in April 2002 after issue of the construction licence.
- Fractures (faults and joints) were documented in the site road batters and in the reactor building and neutron guide hall excavations
- See Figure 6.1
- Faults generally strike north-northeast
- Faults range in dip separation from 0.005 to 1.3 metres
- The main focus of the investigation became faults exposed in the reactor building and neutron guide hall excavations

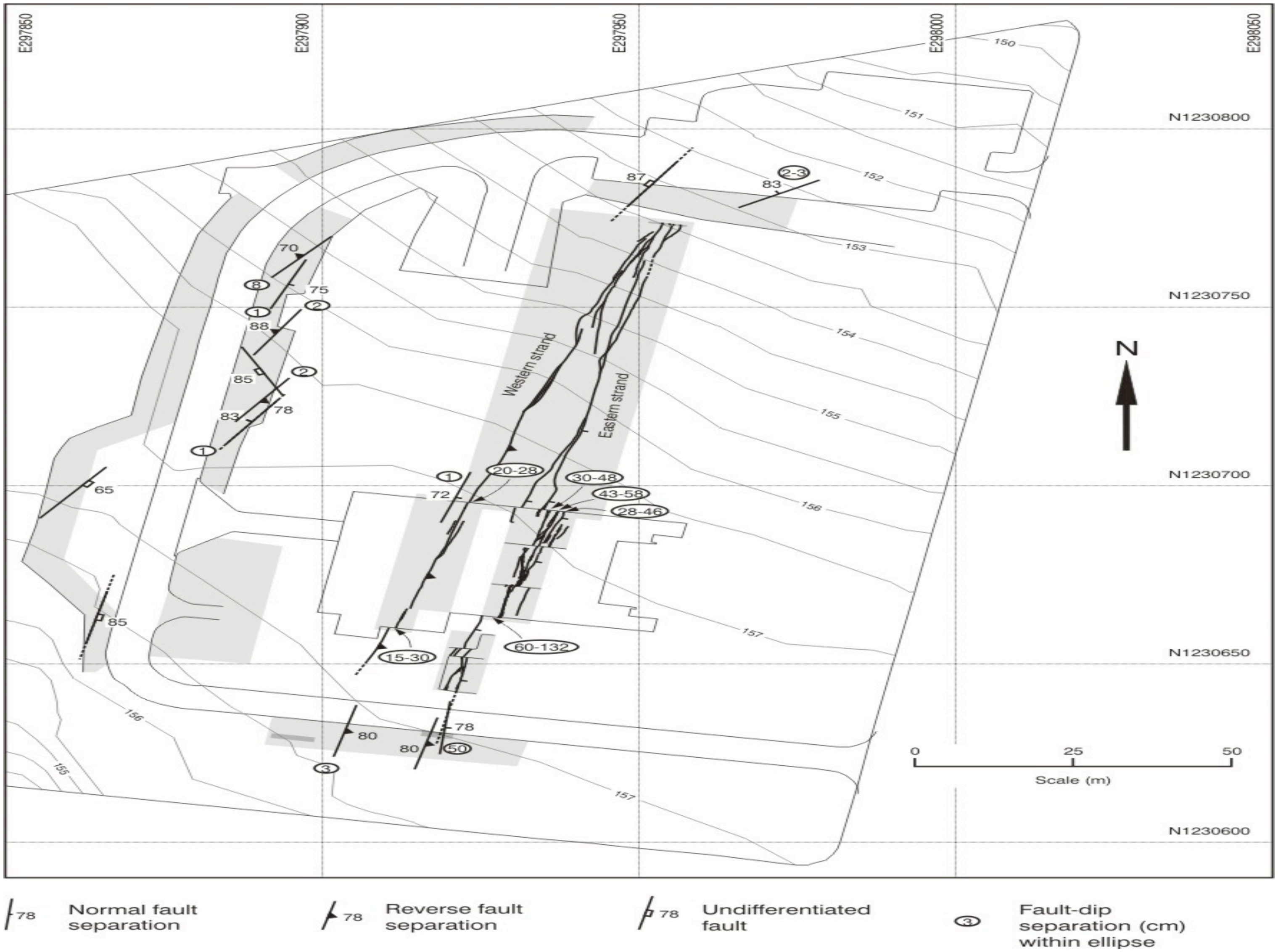

E297850
E297900
E297950
E298000
E298050
N1230800
N1230750
N1230700
N1230650
N1230600
Western strand
Eastern strand
N
0
25
50
Scale (m)
Normal fault separation
Reverse fault separation
Undifferentiated fault
Fault-dip separation (cm) within ellipse

Fig. 6.1

Eastern Fault Strand

- Characterised by
  - a narrow fault zone visible on the southern wall of excavation but wider fault zone visible on northern wall
  - mean strike north-northeast
  - dip separation of 1 to 1.3 m
- Detailed mapping of faulting was undertaken
- South wall Figure 6.2 (photo) and 6.4 (map)
  North wall Figure 6.5 (map)

Fig. 6.2

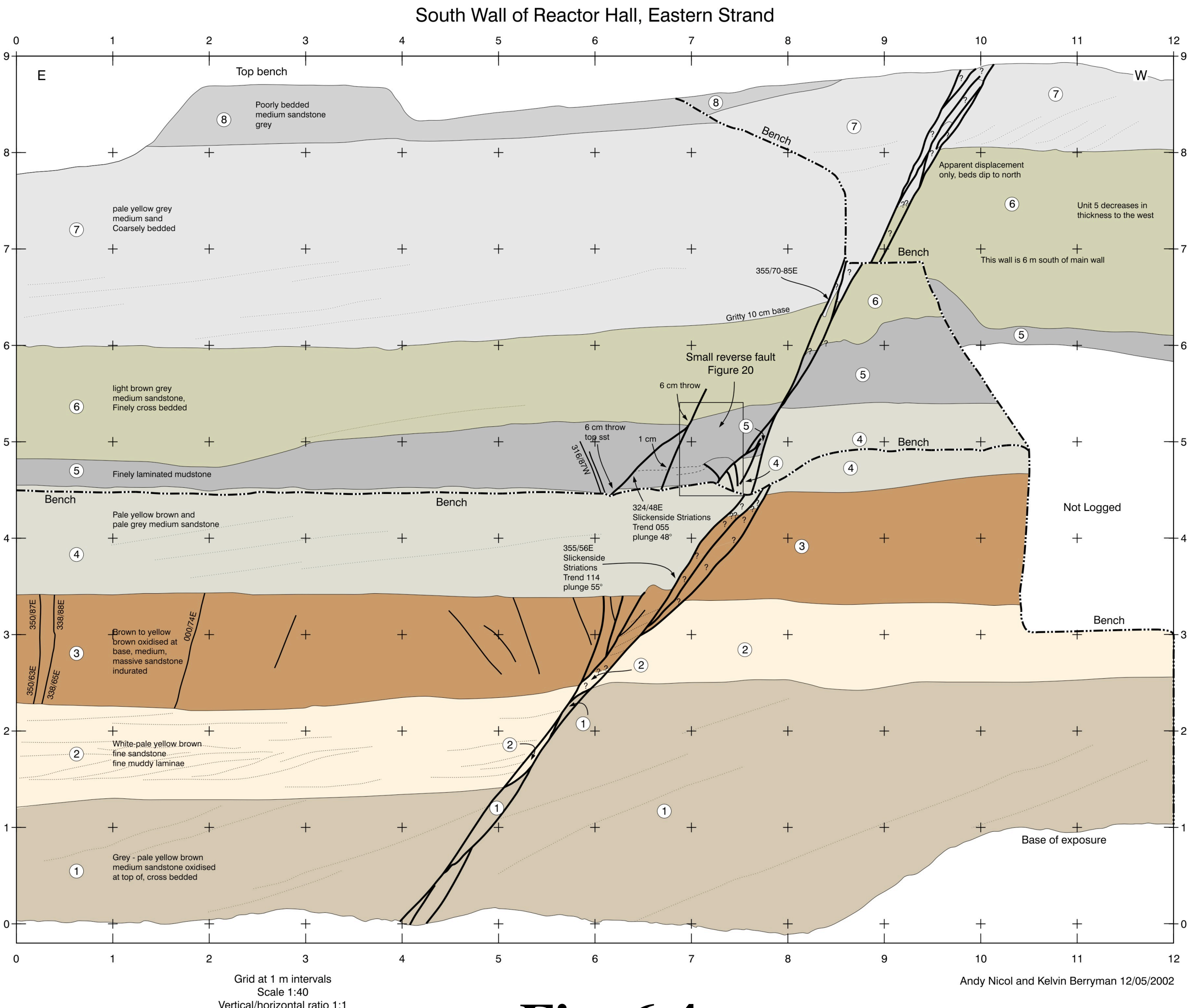
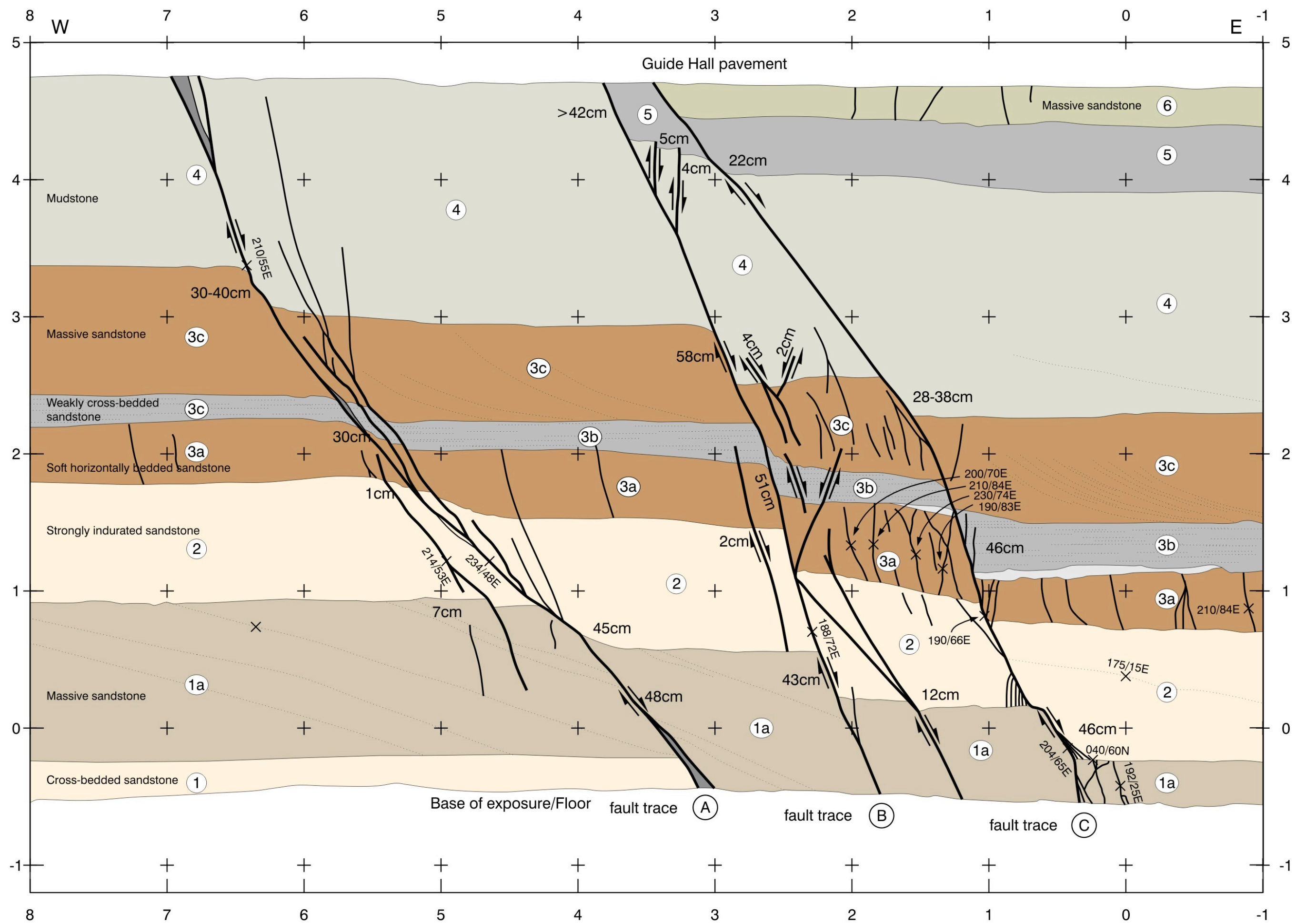

South Wall of Reactor Hall, Eastern Strand
E
W
Top bench
Poorly bedded medium sandstone grey
pale yellow grey medium sand Coarsely bedded
light brown grey medium sandstone, Finely cross bedded
Finely laminated mudstone
Bench
Pale yellow brown and pale grey medium sandstone
Brown to yellow brown oxidised at base, medium, massive sandstone indurated
White-pale yellow brown fine sandstone fine muddy laminae
Grey - pale yellow brown medium sandstone oxidised at top of, cross bedded
350/87E
338/88E
350/63E
338/65E
000/74E
316/87W
6 cm throw top sst
1 cm
6 cm throw
Small reverse fault Figure 20
Gritty 10 cm base
355/70-85E
324/48E Slickenside Striations Trend 055 plunge 48°
355/56E Slickenside Striations Trend 114 plunge 55°
Apparent displacement only, beds dip to north
Unit 5 decreases in thickness to the west
This wall is 6 m south of main wall
Not Logged
Base of exposure
Grid at 1 m intervals
Scale 1:40
Vertical/horizontal ratio 1:1
Andy Nicol and Kelvin Berryman 12/05/2002

Fig. 6.4

North Wall Reactor Hall, Eastern Strand



Grid at 1 m intervals
Logging Scale 1:40
Vertical/horizontal ratio 1:1

Robert Langridge and Simon Cox 19/06/2002

Fig. 6.5

Western Fault Strand

- Characterised by
  - a narrow fault zone visible on both north and south walls of the excavation
  - mean strike north-northeast
  - dip separation of 0.25 to 0.30 m
- Detailed mapping of faulting has been undertaken
- South wall Figures 6.7 (photo) and 6.8 (map)
- North wall Figure 6.9 (map)

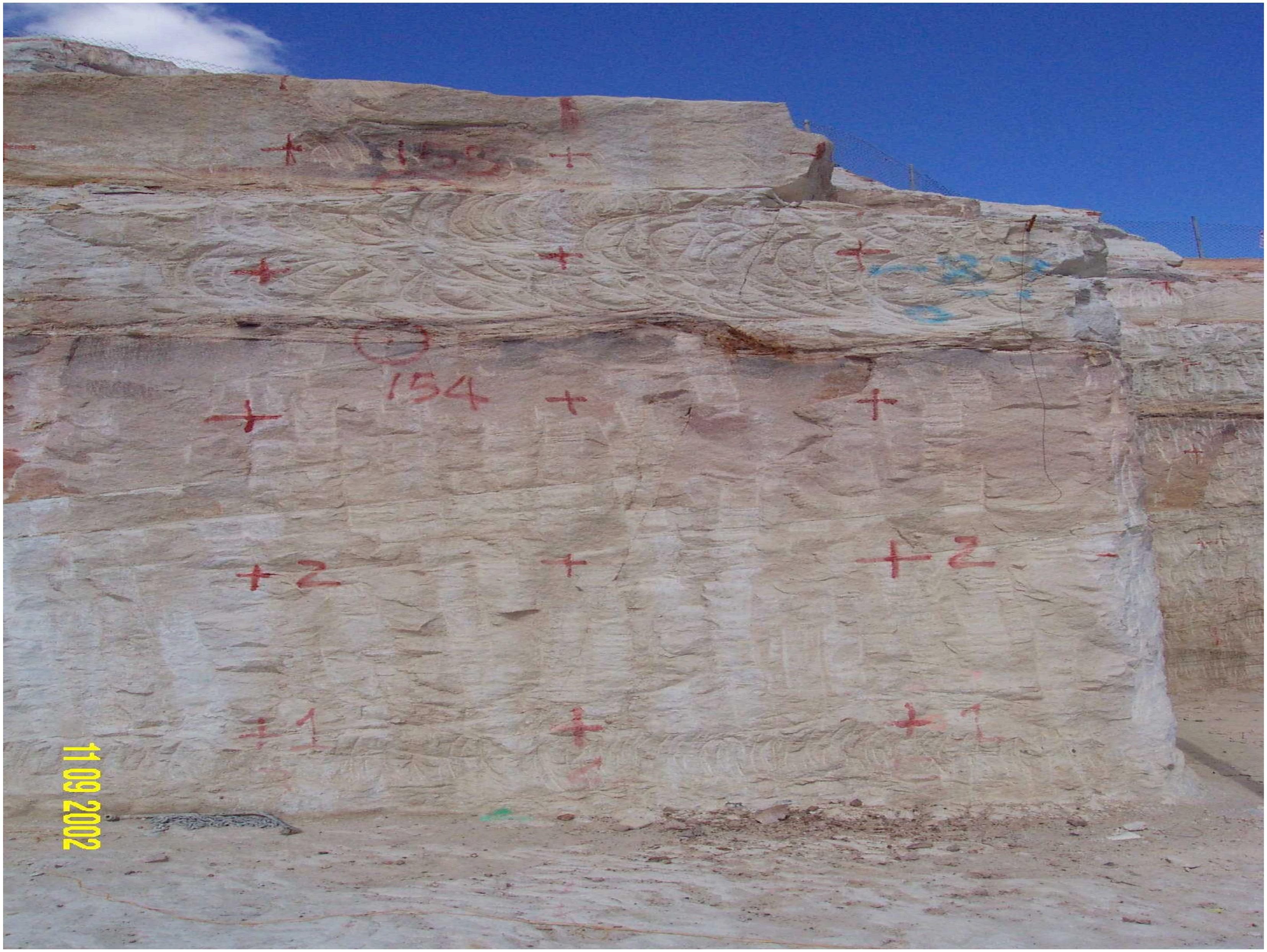


Fig. 6.7

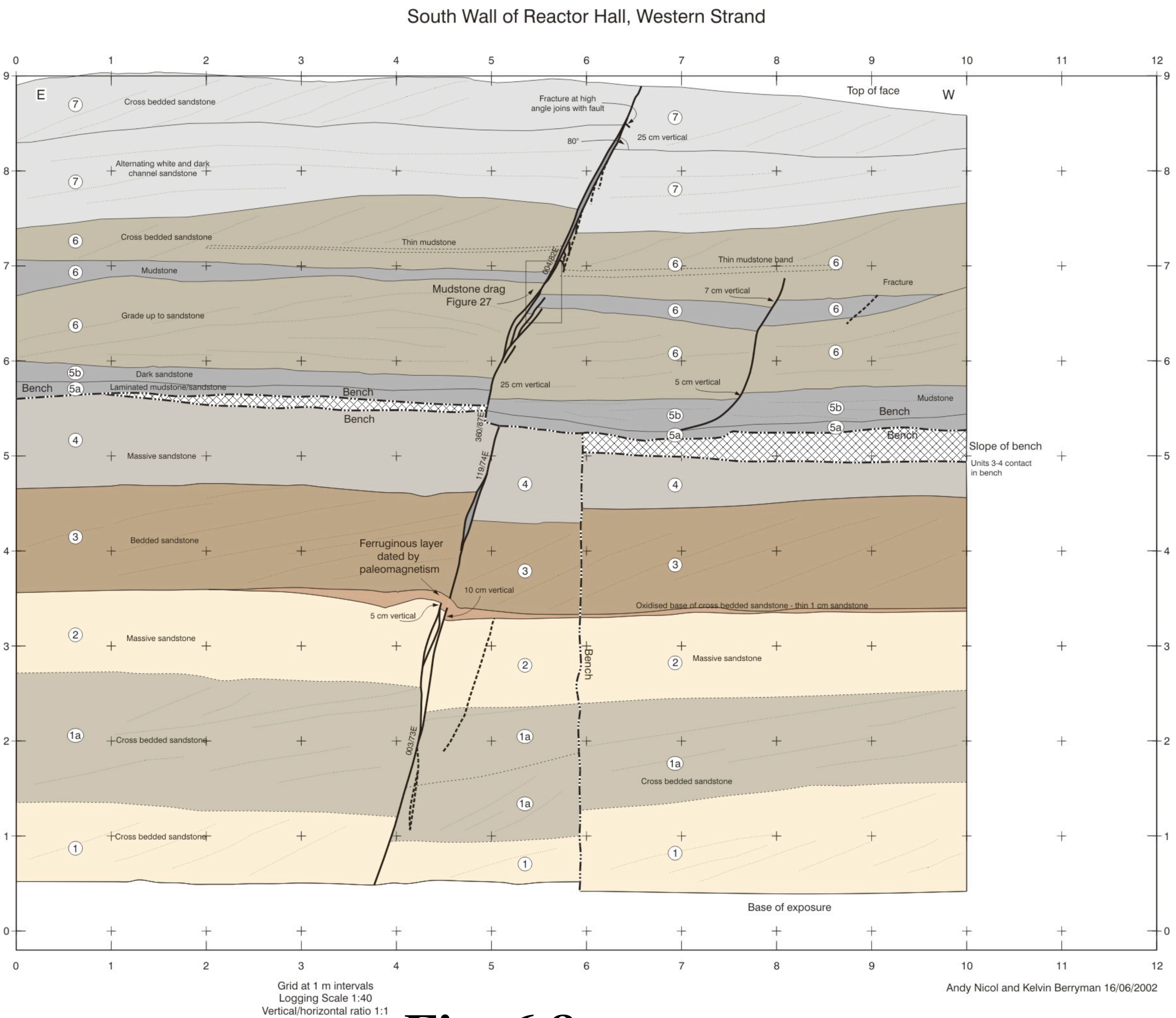

South Wall of Reactor Hall, Western Strand
E
W
Top of face
Cross bedded sandstone
Alternating white and dark channel sandstone
Fracture at high angle joins with fault
80°
25 cm vertical
Cross bedded sandstone
Thin mudstone
Mudstone
Thin mudstone band
Fracture
7 cm vertical
Mudstone drag Figure 27
Grade up to sandstone
Dark sandstone
Laminated mudstone/sandstone
25 cm vertical
5 cm vertical
Mudstone
Bench
Slope of bench
Units 3-4 contact in bench
Massive sandstone
Bedded sandstone
Ferruginous layer dated by paleomagnetism
10 cm vertical
5 cm vertical
Oxidised base of cross bedded sandstone - thin 1 cm sandstone
Massive sandstone
Cross bedded sandstone
Base of exposure
Grid at 1 m intervals
Logging Scale 1:40
Vertical/horizontal ratio 1:1
Andy Nicol and Kelvin Berryman 16/06/2002

Fig. 6.8

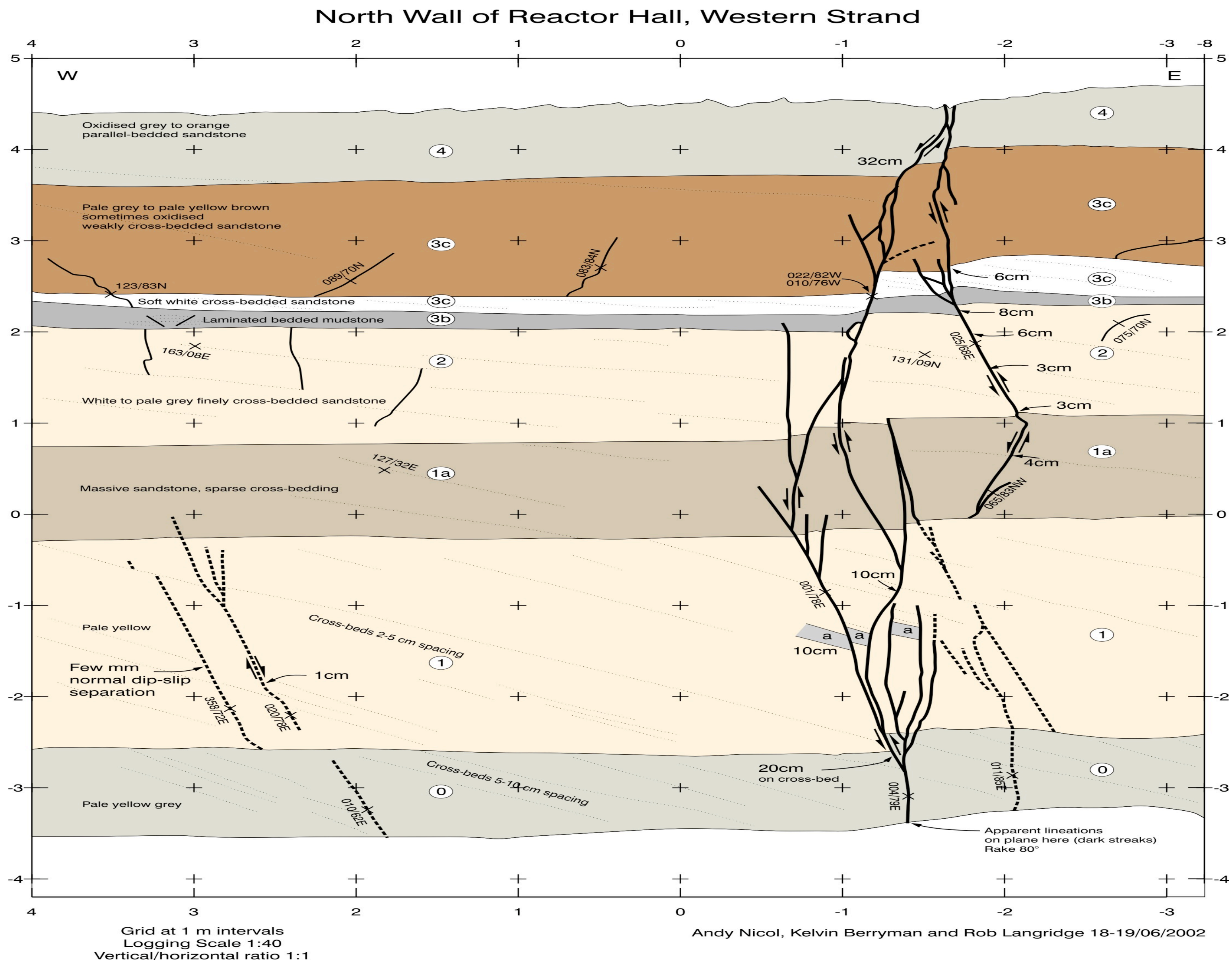

North Wall of Reactor Hall, Western Strand
W
E
Oxidised grey to orange parallel-bedded sandstone
Pale grey to pale yellow brown sometimes oxidised weakly cross-bedded sandstone
Soft white cross-bedded sandstone
Laminated bedded mudstone
White to pale grey finely cross-bedded sandstone
Massive sandstone, sparse cross-bedding
Pale yellow
Cross-beds 2-5 cm spacing
Few mm normal dip-slip separation
1cm
Pale yellow grey
Cross-beds 5-10 cm spacing
32cm
6cm
8cm
6cm
3cm
3cm
4cm
10cm
10cm
20cm on cross-bed
Apparent lineations on plane here (dark streaks) Rake 80°
123/83N
089/70N
083/84N
022/82W 010/76W
163/08E
131/09N
025/68E
075/70N
127/32E
065/83NW
001/78E
358/72E
020/78E
010/62E
004/79E
011/85E
Grid at 1 m intervals
Logging Scale 1:40
Vertical/horizontal ratio 1:1
Andy Nicol, Kelvin Berryman and Rob Langridge 18-19/06/2002

Fig. 6.9

Interpretations

- Both the eastern and western strands were formed during the opening of the Tasman Sea i.e. 53-83 million years ago, and inhomogeneity in the strata or the stress field influenced the nature of the movement on the western strand – supported by steepness of fault plane, appearance of fault in opposite wall and nearby dykes, OR
- The eastern and western strands are part of a system that initiated as a normal fault system, formed during the Tasman Sea opening 83-53 million years ago, with reverse reactivation occurring on one of the strands, and possibly both.
- Each interpretation had expert support!!

Dating approaches

- Three approaches were used to constrain the age of the faulting in the foundation excavation for the RRR.
- One was to trace the fault to an area where there was overlying material that could be studied, both in terms of geomorphology and for dating purposes.
- The second was to analyse borehole material to date a pervasive deep weathering episode that followed fault movement.
- The third was to date a ferruginous layer that crossed the main fault strand.
- An assessment of the age of nearby related dykes was also made

Dating methods

- Optically stimulated luminescence (OSL) to date the unfaulted strata that overlie the fault in trench 4.
- K-Ar dating of the fault gouge and dyke material
- Fission track and (U-Th)/He dating to provide information on the timing of deep erosion of the area.
- Paleomagnetic dating using the magnetic signature of the rocks and relating that to the information known on magnetic reversals and on movements of the earth’s magnetic pole

Overlying material

- A series of minor excavations were made across the site of the NGH and to the north of the NGH to track the faults to an area of undisturbed land (Figure 6.1)
- A trench was excavated to the north of the site so as to expose the converged eastern and western fault strands in the bedrock and to expose a significant depth (approx 1 to 2m) of overlying soil (See Figure 8.1)
- The regolith above the bedrock is not, in any way, displaced by the fault movement in the bedrock

Trench 4 North Wall
Trend: 067° True
Grid projected onto walls S/14°E

01/08/02
R. J. VanDissen
D. B. Townsend

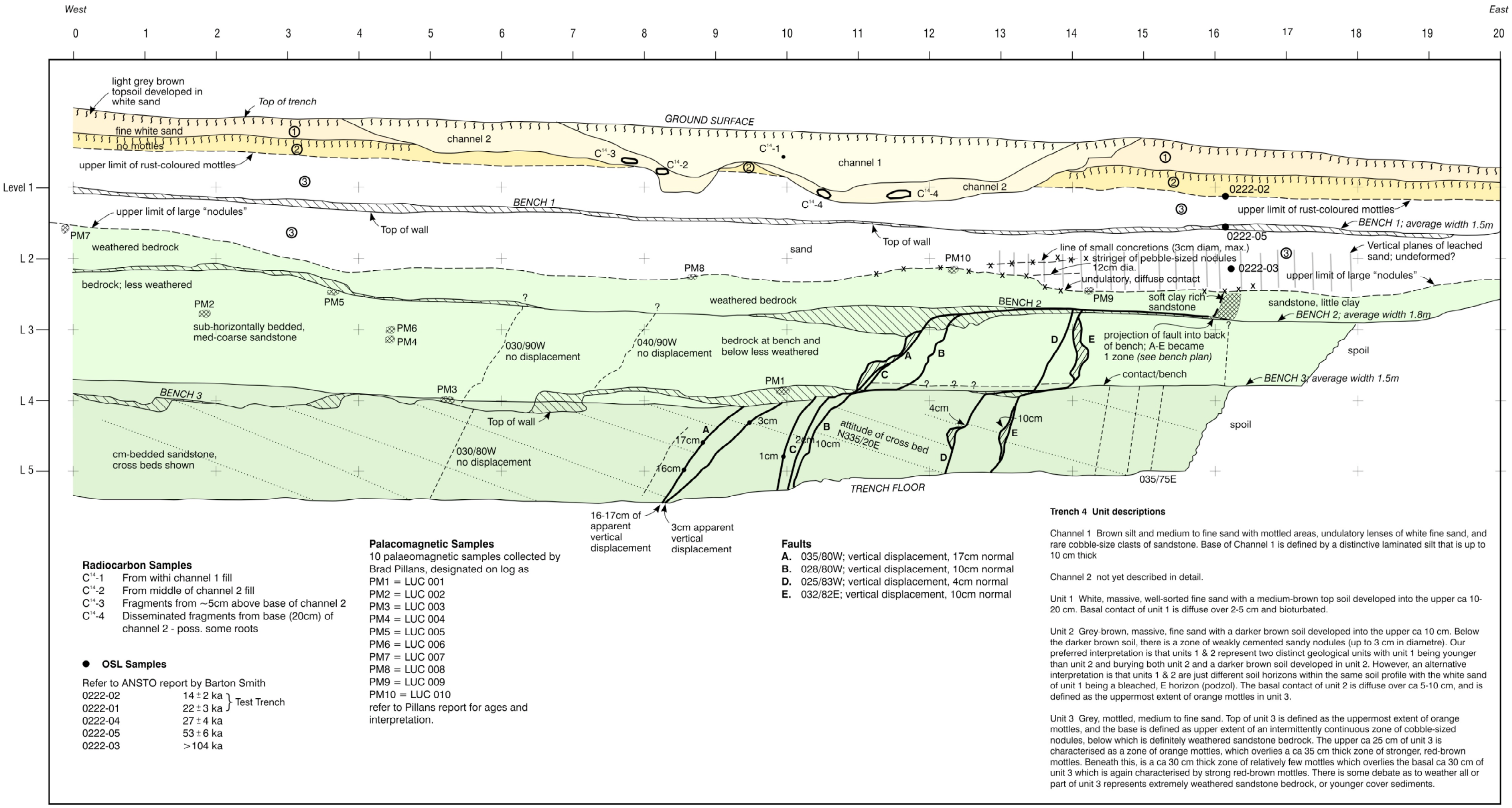


Fig. 8.1

OSL dating of material in the trench

- OSL can be used to estimate the burial age of sediments because grains of quartz accumulate a trapped-charge population due to the effects of ionizing radiation from the surrounding environment.
- The results provide a consistent picture of the age of the material in the fault and overlying the fault
- Samples at 0.4m and 0.6m taken from homogenous grey/brown sands gave ages of 14,000 and 22,000 years.
- The remaining samples were taken from mottled brown sands from 0.8 to 1.5 m depth. These gave ages of 27 ± 4, 53 ± 6 and >104,000 years.
- GOOD but not good enough!

K-Ar dating on gouge and dyke material

- Clays in the eastern fault gouge, either side of the fault and nearby dykes were sampled for potassium-argon dating. This is based on radioactive decay and uses the ratio of K40 to Ar40.
- The calculated ages were:
  - Fault gouge - 89+/- 2 million years
  - Dyke materials - 116+/- 2 million years
  - Either side of fault - 121+/- 2 and 107+/- 2 million years
- All materials just before Tasman Sea opening but does not rule out later movement

Fission Track and U-Th dating

- **Deep weathering** - Bleaching and ferruginous cementation along various fault planes suggest that the fracture planes of the faults were already in existence during the deep weathering process. Deep weathering was from 35-10 million years.
- **Dating of borehole materials** - dating of detrital apatites from sandstones obtained from the deepest (ca 50m) of the test boreholes at the site were studied by both the Fission Track and (U-Th)/He methods.
- Apatite fission track (AFT) results for three samples gave ages varying from 69±4 million years to 75±4 million years

Fission Track and U-Th dating

- The liberated Helium gas volumes for these samples yield replicate ages (within error) and have a mean helium age of ~ 42 million years.
- Fission track dating on apatite relates to cooling through the interval 110°-60°C and (U-Th)/He dating to cooling through approximately 80°-40°C, so that it is expected the ages would occur in this relative sequence during a normal cooling pattern.
- **<u>Conclusion from borehole material</u>** - A period of rapid cooling was experienced by the sandstones in this area between about 85 and 65 million years. Thereafter, cooling was very slow until the present day.
- *Strong supporting evidence*

Paleomagnetic dating

- The formation of secondary iron-oxides by chemical weathering processes provides a means to apply paleomagnetic techniques to date regolith materials. A Chemical Remanent Magnetisation (CRM), aligned with the Earth's magnetic field, may be acquired by mineral grains
- By using the Geomagnetic Polarity Time Scale (GPTS)_- reverse polarity CRM's predates 780,000 years, and as such can provide a useful minimum age in regolith materials

Paleomagnetic dating

- By comparison with the Australian Apparent Polar Wander Path (AAPWP) - can provide a useful minimum age in regolith materials - paleomagnetic poles can be calculated from the remanence directions, which in turn can be used to derive weathering ages by comparison with paleomagnetic poles of known age.
- Rocks exposed in excavations at Lucas Heights have been weathered in the past, with zones of red-brown ferruginization evident to depths of several metres

Paleomagnetic dating samples

- Group 1: Red-brown zones of oxidised bedrock from across the area where the fault strands merge in the northern end of the site.
- Group 2: Red-brown zones of oxidised bedrock from the undisturbed layers in the trench.
- Group 3: A ferruginous layer in the south wall of the reactor building excavation, which crosses both faults and post-dates fault movement since it is not displaced by the fault. Figure 6.7a.

Fig. 6.7a

Paleomagnetic dating results

- Paleomagnetic results demonstrate that secondary iron oxides have reverse polarity magnetisations that predate the Brunhes/Matuyama paleomagnetic transition at 780,000 years.
- A reversely magnetised ferruginous layer in the south wall of the reactor excavation post-dates fault movement. The fault has therefore not moved in the last 780,000 years.

- The paleomagnetic pole calculated for this unfaulted ferruginous layer crossing the fault yields an age estimate of 5-13 million years old. The fault has therefore not sustained surface rupture for at least the last 5 million years. Figure 8.3 and Figure 8.4.

Geomagnetic Polarity Timescale

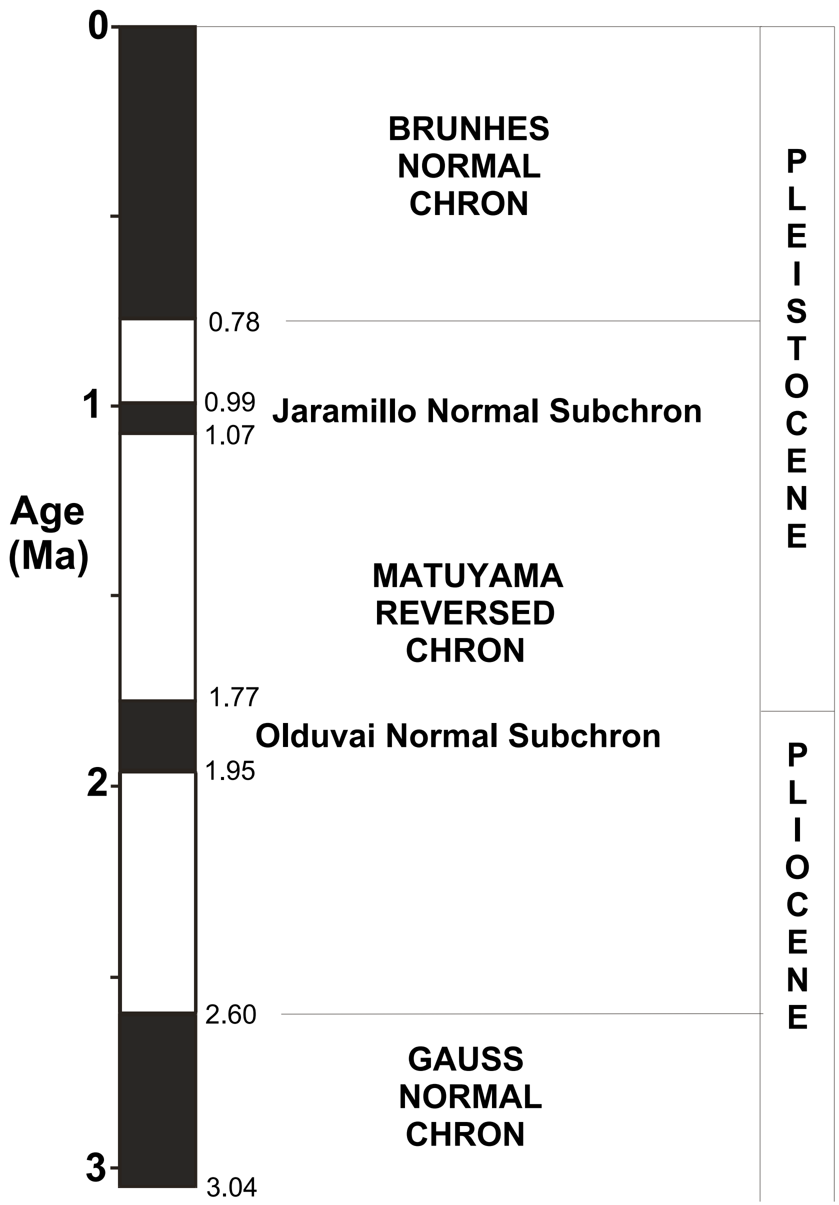


Figure 8.3 – Geomagnetic Polarity Timescale for the last 3 Ma

Samples plotted on Polar Wander Path

LUCAS HEIGHTS

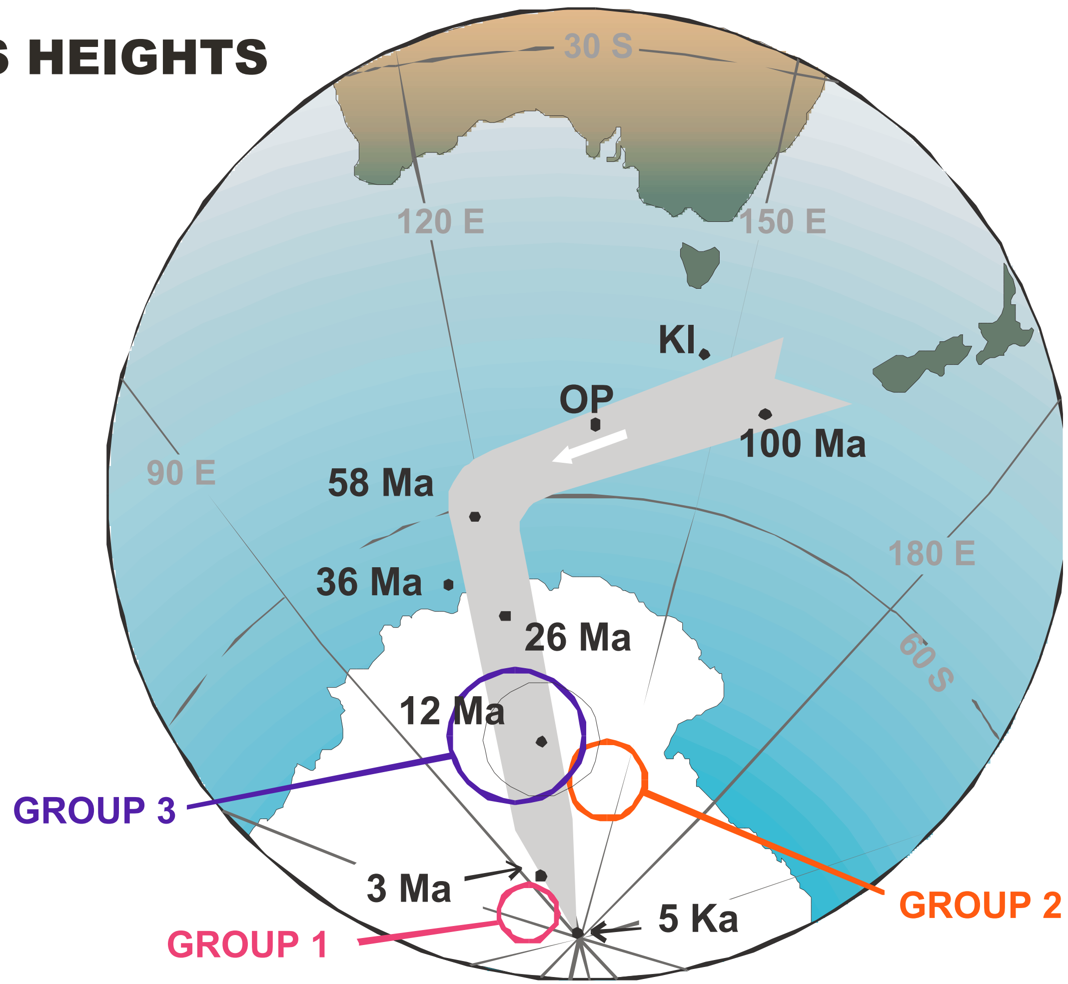


Fig. 8.4

Capability of the fault

- The IAEA and US NRC provide criteria for determining the capability of a fault.
- These criteria relate to last movement, proximity to a capable fault and magnitude of seismic event at such a fault.

Capability of the fault

It shows evidence of past movement or movements of a recurring nature within such a period that it is reasonable to infer that further movement at or near the surface can occur. (In highly active areas, where both earthquake and geological data consistently reveal short earthquake recurrence intervals, periods of the order of tens of thousands of years may be appropriate for the assessment of capable faults. In less active areas, it is likely that much longer periods may be required.)

The most recent fault movement is at least 5 million years old and the fault shows no evidence of past movement or movements of a recurring nature

Capability of the fault

A structural relationship has been demonstrated to a known capable fault such that movement of the one may cause movement of the other at or near the surface.

The nearest known possible Capable Fault to the site fault is the Lapstone Structural Complex located approximately 35 km west of the site. Because of this substantial distance no secondary movement is expected to occur on the site fault. Extensive investigations have proved conclusively that similar zones to the Lapstone Structural Complex do not extend further east towards Lucas Heights.

Capability of the fault

The maximum potential earthquake associated with a seismogenic structure, as determined in section 4 (of the IAEA guide), is sufficiently large and at such a depth that it is reasonable to infer that movement at or near the surface can occur.

The only seismogenic structure is the LSC. The conservative choice for the repeat time for the LSC is 11-27 ka (Alliance 1999 report), so the LSC will have ruptured many times during the past 5-13 million years and clearly has not triggered any slip at the RRR site.

Therefore, the site fault cannot be classified as Capable by the criteria established by the IAEA (or USNRC) for the siting of nuclear power plants.

Conclusions

- An extensive geological analysis has been undertaken, consistent with international criteria
- The faults discovered in the reactor excavations have been extensively studied and the minimum age of the last movement has been determined as 5 million years, consistent with the thermochronology results.
- Therefore these faults are clearly not potential seismic sources.
- There is no need to alter the outcomes of the analysis already performed as part of the probabilistic seismic hazard assessment and used in the design of the reactor.
- There is no change required to the design hazard spectrum or the facility design, put forward in the PSAR in May 2001.

Outcome

- Results were subject to detailed review by the regulator using national and international experts
- The process was considered to be thorough, transparent, defensible and to have significantly enhanced the understanding of the geology and seismology of the region.
- Agreement was obtained to restart construction in November 2002 – 4 months after discovery of the faults.
- The construction is due for completion by the end of 2004, commissioning in 2005 and full power operation in 2006


12/11/2002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