

**Review of ANSTO Submission to ARPANSA
on Site Geological Investigations of Lucas Heights**

**by
Geoscience Australia**

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**This report needs to be read in conjunction with ANSTO's 'Response to Consideration
by Geoscience Australia of ANSTO Submission to ARPANSA on Site Geological
Investigations of Lucas Heights'**

October 2002

Geoscience Australia
Initial Review of Submission to ARPANSA on Site Geological Investigations of
Lucas Heights
Questions and Clarifications Requested

Prepared by Geoscience Australia Review Team
24 September 2002

Introduction

The review comments and questions posed presented here represent our initial assessment of the material prepared by ANSTO and presented to us by ARPANSA on 16 September 2002. There may be additional issues that arise from further investigation.

1. Interpretation of palaeomagnetic results.

Dr Pillans presents a good case that the samples analysed for palaeomagnetism record a reverse magnetic polarity, and hence were deposited/formed prior to 780ka. However, it has not been clearly demonstrated that the ferruginous layer sampled for the Group 2 analyses, and purported to postdate faulting, does indeed postdate faulting. In the geological assessment made by IGNS, this relationship is also asserted without support (A1, p13).

A close inspection of the ferruginous layer in figures 6.7a and 6.7b shows it to be conspicuously curved where it is intersected by the fault plane. The curvature also looks consistent with reverse slip on the fault plane. Further inspection of the ferruginous layer to assess whether it has been disturbed by the fault plane may be warranted. A **site inspection** is the best means of doing so. These relations are of the utmost importance as this relationship is the strongest evidence for there having been no movement on the fault for more than 780 000 years. Without this constraint, the minimum age bound for the last fault movement reduces to >104ka (also see Point 3 below).

Furthermore, it has it been clearly demonstrated that the Group 3 samples formed at the same time as the saprolite, and indeed that faulting postdates the development of the saprolite (see also Point 2). The significance of the Group 3 samples in relation to the faulting is therefore brought into question.

The precise context of the Group 1 samples in relation to faulting or to other weathering features in the site was not given (A1, p13). No conclusion relating their inherited magnetism to faulting or weathering features could therefore be made.

2. Confusion over regolith

The evidence provided in the report is sufficient to justify the authors' conclusion that deposition of the sediments overlying the saprolite in Trench 4 post-dates faulting. A minimum OSL age estimate of >104ka for the last fault movement is therefore supported.

However, the implication that bleaching and iron oxide cementation along fault planes is contemporaneous with saprolite development (p30, section 8.4), and the subsequent

conclusion that the faulting postdates the development of the saprolite (p30, section 8.4; p36, point 9), are not supported by the evidence provided.

It has been asserted in several places in the submission (e.g. p24, section 8; p25, section 8.1.1; p30, section 8.4; p33, section 8.4.5; p36, point 9) that the faulting (particularly in Trench 4) pre-dates the development of the saprolite (the deep weathering profile referred to by Gleadow et al, 2002?). In the thermochronology section (Section 8.4), this assertion appears to be based upon the correlation of '*localised zones of bleaching and ferruginous cementation along various fault planes*' with the saprolite developed at the site. A similar observation is made in the Palaeomagnetism section (p28, Section 8.3).

1. What criteria were applied to discount the possibility that movement might have occurred subsequent to the bleaching along fault planes? Might not the faults have first formed during the opening of the Tasman Sea, been subsequently bleached, then reactivated in a reverse sense at a still later date?
2. Why need there have been only one bleaching/weathering event along fault planes? Could not the tendency of faults to localise and provide pathways for water result in multiple and unrelated bleaching and cementation events throughout time resulting from local fluctuations in the water table, or other phenomena? Active bleaching and cementation along discontinuities exposed in the Northside Storage Tunnel, M5 east tunnel, and the Eastern Distributor provide evidence that this process is not restricted to a single period of geologic time characterised by slow weathering. The scenario in the above Point 1 might therefore be further complicated if, subsequent to reverse reactivation, the fault was re-bleached and/or cemented.

The apparent lack of an expression relating to faulting at the saprolite/sediment interface was also taken as evidence that faulting postdates the development of the saprolite (p27, section 8.2.1; Attachment 6 of the additional geological investigations report, by Colin Pain). This is in spite of Colin Pain referring to the contact as '*indistinct to diffuse*'.

It is not clear to me why a lack of expression for faulting at this contact should necessarily require the conclusion that faulting postdates saprolite development. As stated in the report (p33, section 8.5; Attachment 6 of the additional geological investigations report, by Colin Pain), it is possible that the sediment overlying saprolite in the trench could have been removed and replaced many times. Could not any offset developed in the saprolite due to reactivation of the fault in the underlying bedrock have been planed off as a result of one, or several, of these events? Would such an offset be noticed given the '*indistinct and diffuse*' nature of the contact?

Assuming the saprolite surface had been planed, We are not convinced that a small reverse reactivation of the fault, producing a displacement of the saprolite/bedrock contact, would be easily detectable given the gradational nature of saprolite/bedrock boundaries and the subjective manner in which they are usually assigned (in the case of Trench 4, the boundary between bedrock and saprolite appears to have been arbitrarily assigned to the top of a bench). We think this uncertainty is reflected in the conservative manner in which the relationship was reported by Colin Pain: '*...it is **likely** that there has been no movement since the formation of the saprolite (the lowest layer above the bedrock).*' The distinction between *certainty* and *likelihood* is important in this case, but has been ignored in the subsequent assertions made by the geochronological fraternity.

It should also be noted that the fault in Trench 4 dips to the west in contrast to the easterly dip of the other mapped normal faults (A1, p14). Although along strike from the easterly and westerly fault strands, it is debatable whether the structure is a direct continuance of them. The IGNS team suggest that it may be a 'stepover' or 'relay-ramp'. Such a feature may be unsuitable for reactivation in circumstances under which the main structure might reactivate. This supposition is circumstantially supported by the observation that reverse offset on the westerly strand dies away towards the north (A1, p15). That being said, the fault as revealed in Trench 4 does bear some similarity to the upper 5 metres of the western fault strand exposed on the northern side of the reactor hall excavation.

The above observations again highlight how dependent conclusions about fault activity are on the ferruginous material in the northern wall of the reactor hall, for which a minimum paleomagnetic "age" of >780 000 years is inferred.

3. Factual error in the summary

On page 6, it is stated that '*Palaeomagnetic results of ferruginous material laid down across the fault and post dating any movement on the fault...yield a minimum age of 9 million years and not younger than 5 million years*'. This statement is highly misleading and is not in any way supported by the information provided in the report. The palaeomagnetic age of 5-13 Ma was obtained upon a ferruginous layer precipitated out along bedding in **bedrock** (Fig. 6.7a and b). In the report, we see no evidence that sedimentary material '*laid down across the fault*' was dated by this method.

4. The fission track data does not appear to be relevant to the problem.

The fission track and (U-Th)-He age data from the bore holes do not appear to be particularly pertinent to the problem at hand since they relate to the exhumation and cooling history of the Hawkesbury Sandstone as a single coherent entity and afford little information about when the fault last moved. The data apply at the district rather than local scale (ie do not appear to be particularly site specific). Nevertheless, the data support (but do not prove) the proposition that normal faulting most likely occurred in relation to the extensional events that accompanied opening of the Tasman Sea and thus dates back to the Cretaceous period. This event is reflected in the period of rapid cooling observed in the thermochronological profile.

We contend that the evidence for discolouration along the faults could have happened during any number of events, and need not be linked to the supposed time of deep weathering. Gleadow & Sandiford's argument for stating that a link exists is not articulated beyond their stating that they could find '*no evidence that any fault movement had occurred since the weathering episode*' (A3 - p2 of 3). What would they expect to find if movement had occurred, and would they recognise it? Is the weathering observed related to one, or to several fluid events (see also above point 3)? Again, without the link between the discolouration and cementation associated with the fault planes and the deep weathering profile examined by fission track dating, the fission track data has no bearing on the current problem.

Further, the minimum age bound of 10Ma reported in the thermochronology section is not supported. It presumably relates to geologic data presented by Herbert, (1980). The basis for presenting this age should be made clear.

5. The relevance of dykes used as support for interpretation 1 is not clear.

On page 5 of the report, the first interpretation of the data includes reference to undeformed dykes occupying fractures with a similar orientation to the faults crossing the RRR site. It is not clear how the data supports the interpretation. We have seen dykes in similar structural contexts elsewhere in the Sydney Basin that have been highly deformed during reverse reactivation of the initially normal structures in which they are hosted. Do the authors contend that because these dykes are not deformed, then the faults 400m away also have not been reactivated?

6. The opportunity to directly date fault materials has not been taken.

No attempt was made to date actual fault materials. The normal fault (eastern strand) contains minor fault gouge that might have sufficient clay component for K-Ar or ^{39}Ar - ^{40}Ar dating. There is no stated reason for discounting these methods. Would not an old age from the fault plane itself remove any doubt that normal faulting occurred in the distant past?

There are clearly difficulties applying such techniques in instances where the original fault gouge may have been affected by ground waters and deep weathering but to list potential dating methods and then decide to employ only a few of these methods requires some explanation. The result is that the case for no recent movement on the fault planes depends to a large degree on the weathering profile and its constituent components such as the ferruginous layer dated at >780, 000 years.

Geoscience Australia
Review of Submission to ARPANSA on Site Geological Investigations of
Lucas Heights
Comments on response of ANSTO to Issues Raised by Geoscience Australia

Prepared by Geoscience Australia Review Team
17 October 2002

Geoscience Australia (GA) is pleased to provide the below reply on the additional information supplied by ANSTO (received by GA on 4/10/02) in response to queries raised by us concerning the original submission to ARPANSA (dated 12/09/02). The summary below indicates that we are generally satisfied with the supporting information provided by ANSTO. The evidence presented appears to support the conclusion that the minimum age of significant fault displacement is constrained by the age of deposition of the ferruginous layer at 9 ± 4 Myr.

GA will incorporate this information in a final report to ARPANSA, together with relevant observations from our preliminary report of 20/09/02 (revised 24/09/02).

Point 2 Interpretation of palaeomagnetic results

In their response to our concerns, the ANSTO team provide detailed additional information on the locations from which individual Group 2 palaeomagnetism samples were taken within the “folded” ferruginous layer. They also provide a simple and elegant demonstration that the observed clustering of the palaeomagnetic remanence orientations derived from the samples would not be manifest if significant rotation of the ferruginous layer had occurred subsequent to its formation. Their analysis also demonstrates that the secondary oxides deposited on the faulted bedding layer remote from the fault formed contemporaneously with the oxides immediately adjacent to, and apparently controlled by, the fault.

In summary, we consider that the additional data provided by the ANSTO team provides a compelling case that no significant internal rotation of material has occurred within the Group 2 oxidised layer for at least 9 ± 4 Myr. This in turn suggests that no significant movement has occurred since that time on the fault over which the oxide layer is draped.

Point 3 Interpretation of the regolith

GNS provide a comprehensive explanation of the geometry and properties of the regolith and bedrock materials found in Trench 4 in response to our query. We are satisfied that the most plausible explanation of the evidence provided is that the deposition of the sediments overlying the saprolite in Trench 4 post-dated faulting. A minimum age of faulting of $>104,000$ years is therefore supported, based upon the OSL results (Smith, 2002).

In light of the supplementary discussion provided, we agree with GNS that the faults in Trench 4 are likely to be kinematically related, if not directly correlatable, to those exposed in the reactor hall excavation.

Point 4 Statement on page 6 of the summary

We agree that the statement on page 6 of the summary could be better worded as “*Palaeomagnetic results of ferruginous material precipitated out along bedding in the bedrock across the fault and post dating any movement on the fault...*” However, a more accurate statement would be “***Results of palaeomagnetic analysis indicate that the ferruginous material precipitated out along bedding in the bedrock across the fault and post date any significant movement on the fault...***” better represents the evidence.

Point 5 Relevance of the fission track data

We acknowledge that the fission track data could be useful in establishing an overall chronology of the site in which the probable timing of faulting can be *broadly* constrained. The link depends fundamentally on the proxy that movement on the fault has not occurred subsequent to deep weathering, which is in turn related to the integrity of the ferruginous layer from which Group 2 palaeomagnetic samples were taken. Based on supplementary evidence provided by ANSTO (see point 2), it is reasonable to conclude that the ferruginous layer postdates any significant movement on the fault. The link is therefore justified in our opinion. However, the major utility of the fission track results remains in building a body of evidence that the last fault movement occurred in antiquity, rather than providing independent constraint on the last episode of movement.

Point 6. The relevance of dykes used as support for interpretation 1.

We do not take issue with the interpretation that the faults 56m west of the western fault strand along which dykes have intruded might be part of a coherent set of faults. However, the ANSTO team suggests, based on this link, that the undeformed nature of the dyke material supports the interpretation that no major reactivation of the whole set of faults has occurred since dyke emplacement. It is important to realise at this point that we seek evidence for *any* reactivation of the structures intersecting the RRR foundation footprint, not necessarily major reactivation. It does not necessarily follow that a minor reactivation of the eastern of western fault strand might trigger sympathetic movement in a related structure 56m away. We would therefore regard this line of evidence with caution. This in no way diminishes the conclusions regarding the age of reverse faulting deduced from the Group 2 palaeomagnetic samples.

Point 7 Opportunity for directly dating fault materials

We are satisfied that the conclusion from K-Ar dating of gouge, host rock and dyke samples, that an early Cretaceous age for fault movement is favoured “*on at least those faults which could be examined by the method*”, is supported by the evidence. We furthermore agree that there is nothing in the K-Ar evidence, or indeed any of the other geochronological evidence that points to a young age for any of the fault movements. However, the key piece of evidence suggesting that the movement on the faults is old remains the Group 2 palaeomagnetic results.