COLLATING AGES OF CAINOZOIC VOLCANICS TO DETERMINE RATES OF LANDSCAPE DEVELOPMENT

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ABSTRACT
The ages of Cainozoic volcanic rocks and their landscape context can be used to estimate average rates of landscape erosion since eruption. There is no central repository of the ages of the volcanics, so I am collating published and unpublished data for use in determining landscape dynamics in eastern Australia, as part of the Landscape Analysis project of CRC LEME Program 4. This study will result in new insights into landscape evolution, and be useful in determining areas of relatively uniform landscape development, over which the results of detailed regolith investigations can be extended. Relationships between erosion rates and the occurrence of dryland salinity will also be studied, to determine whether this new dataset has a role to play in the prediction of salinisation.

INTRODUCTION
Cainozoic age basalt and other associated volcanic igneous rocks (volcanics) are common throughout the upland areas of eastern Australia. Some are associated with large central volcanoes, reaching hundreds of metres thick, and forming large volcanic landforms such as the Warrumbungle Ranges. At the other end of the spectrum there are remnants of small flows a few hectares in area and only metres thick that originated from local fissures. In addition to extrusive rocks, plugs, sills and dykes that intrude country rock and (rarely) lavas are also locally present. These volcanics form a range of landscape features, including remnants of large volcanoes, topographically-inverted hill caps, fills within extant valleys, and broad lava plains. The preserved rocks vary from fresh to highly weathered.

Fresh samples of the Cainozoic volcanics can be dated by various techniques. The radiogenic isotope K-Ar method has been most commonly used. This uses the concentrations of the radioactive isotope K^{40} and its daughter isotope Ar^{40} to calculate an age of crystallisation of the rock, which is in almost all cases the time of extrusion or emplacement.

In many cases dating has been carried out primarily to assist igneous petrologists to unravel the history of volcanism, and to document the timing of changes of geochemistry of the volcanics. It has been shown (eg Sutherland 1983) that the ages of the large central volcanoes decrease with increasing latitude, suggesting that they represent eruptions from a mantle hot spot over which the Australian plate has been migrating. The smaller flows do not show this type of relationship. However, it has been shown that groups of flows in many areas have a similar age or groups of ages, suggesting that local volcanism took place over limited geological periods, probably from closely-related magma sources (eg Wellman and McDougall 1974).

The age of the volcanics can be used to make interpretations on the rate of landscape evolution, and their distribution can give clues to the palaeolandscape on which they were extruded. The volcanics are generally resistant to weathering and erosion. Many flows that originally flowed down river valleys are now preserved as topographically inverted remnants on hilltops, as the country rock around the flows has preferentially been eroded (eg Young and McDougall 1993, Bishop *et al*. 1985, Spry *et al*. 1999). If the amount of erosion since the time of extrusion of the volcanics, and the age of the volcanics are known, an average rate of erosion or river incision since extrusion can be determined. In addition, the configuration of the lava flows can also be used to help reconstruct the topography and configuration of drainage lines at the time of extrusion (eg Young and McDougall 1993).

As part of the landscape analysis project within CRC LEME Program 4 (salinity) I am collating age data for volcanics in eastern Australia. As at August 2006 I have 850 ages. These will be included in a GIS, along with digital geology showing polygons of Cainozoic volcanics, and Shuttle Radar DEM (and other DEMs where available), which will be used to assess the amount and average rate of landscape development since extrusion. Slow rates of development will probably result in lower local relief and increased preservation of weathering profiles, whereas high rates may be associated with steeper relief and fresher rocks. These contrasting physical conditions will have contrasting groundwater flow regimes, resulting in different distribution and expression of salinity in the landscape. The erosion rate data may also help determine areas of relatively uniform landscape development, and thus areas of relatively uniform regolith over which results from detailed investigations of small areas can be extended.

SOURCE OF DATA

There is no central repository for K-Ar age data in Australia. However, there are many Cainozoic ages published in journal papers and reports, from the late 1960s (when the technique became established) onwards. Amongst the early researchers, Wellman of ANU and BMR, and McDougall of ANU published hundreds of ages, and Webb of AMDEL laboratory is also associated with many determinations. Most of the published data were collated into various summary reports (which included both Cainozoic and older dates) up to the mid-1980s. The Geological Survey of NSW has produced a hard copy summary report of all NSW K-Ar dates up to the mid-1980s (Jones 1986), a scanned version of which is available over the internet. This report is extremely cumbersome to use as samples of all ages are included, the sample numbers or ages are not sorted in any way, nor is there an index of sample numbers. However, the original list was computer based (Microbee 128k computer, Ashton and Tate 'Friday' software), and thankfully this has been migrated into a Microsoft Excel spreadsheet that is now in use at the Survey, and which has been made available to CRC LEME. This spreadsheet appears to have not been updated since the 1986 report.

The Geological Survey of Queensland also has an Excel spreadsheet of K-Ar dates which appears to be relatively up to date, with numerous determinations that are not publicly available elsewhere. The Geological Survey of Victoria published a list of all radiometric age determinations made on their own samples up to the early-mid 1980s (McKenzie *et al*. 1984). More general summaries of ages are presented in general synopses on Cainozoic volcanicity, of which Johnson (1989) is the most complete.

Many other determinations have been made by researchers from Universities and Museums, but not published. We are in the process of contacting these people to see whether they have dates that they are willing to share with CRC LEME for use in the project. At present, there are probably many more published and unpublished Victorian ages to be added (mostly from relatively young volcanics of western Victoria), a good number from Queensland, and a few from NSW. A start has yet to be made on Tasmanian and South Australian data.

DATA AND DATA QUALITY

It is hoped that the collated data will be made publicly available, both as hard copy and spreadsheet files. It is also possible that data may be incorporated into Geoscience Australia's Ozchron database. For these reasons, all available data about the rocks, their ages, and original author's comments have been recorded.

Location

The quality of location data varies enormously. Metric grid references to the nearest 100 m, or lat/long coordinates to the nearest 10 seconds are available for many samples, but some locations are only given as a brief description (eg "north summit of Mount X") or as yard grid references. In the former case, the location of the feature as shown on the 1:100 000 topographic map series or in the Geoscience Australia Gazetteer is used, to the nearest minute. With yard coordinates, the location has been determined on old geological maps showing the yard grid, and an approximate metric grid reference or AGD 66 lat/long determined, usually to the nearest minute or 1000 m.

All location data have been migrated into GDA 94 lat/long coordinates using the "Geod" software available from http://www.lands.nsw.gov.au/LPServices/Surveying/GDA/GEODSoftware.htm. The original location data have also been retained, and a record made of how the GDA coordinates were determined.

Age

Age is recorded mostly in millions (for very young rocks, thousands) of years. Constants used in calculating K-Ar ages from laboratory data were reviewed in 1976 and a new set recommended (Steiger and Jager 1977). Tables for conversion of dates calculated using the old constants are given by Dalrymple (1979). Information on the constants used is given with most published dates, so it is mostly known whether a correction has to be made to the age. The correction required is only a few percent increase in age.

Most ages are also given an error, usually expressed as ± 1 or 2 standard deviations. This refers to the accuracies of the laboratory measurements, not the suitability of the rocks for age determination. Some authors do not state the basis of their error figures.

For the laboratory-determined age to be accurate there must have been no leakage of Ar from the rock or mineral phase analysed. If Ar has leaked, the laboratory determined age will be too young. Only the freshest unaltered rocks are considered suitable for accurate dating. Many authors give an indication of the degree of alteration of the rock, or whether they consider a particular date to be only a minimum age. Author's comments or degree of weathering have been recorded along with the ages.

Other data

Other data recorded include all available analytical data used in the age determination, rock type, mineral phase(s) analysed (including whole rock), form of the rock body (flow, plug, sill etc), whether flows are part of a sedimentary sequence, and original authors' comments about the sample.

DISTRIBUTION OF SAMPLES

The locations of the ~850 determinations so far collected are shown in Figure 1. No Tasmanian ages have been collated to date, and there will probably be many Victorian sites to add.

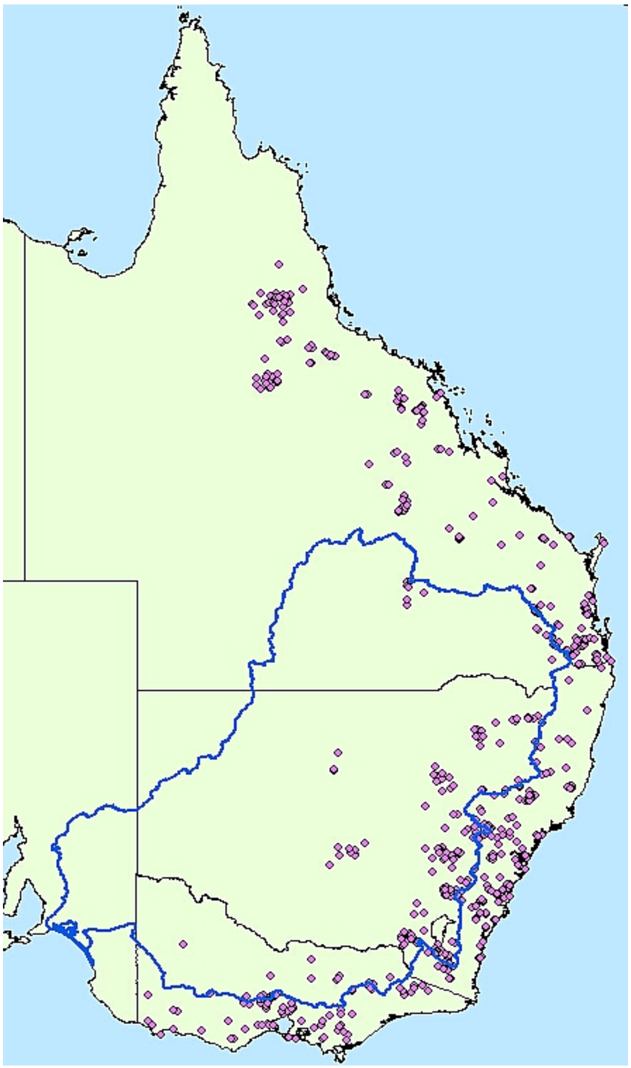

Figure 1. Location of collated dates of Cainozoic volcanics in eastern mainland Australia. Murray Darling Basin outlined.

EXAMPLES OF INTERPRETATION OF PALAEOLANDSCAPE FROM BASALT AGES

Young and McDougall (1993) have described and dated Early Miocene basaltic lavas that flowed along river valleys in the Tumbarumba region of southeast NSW. Reconstruction of the Early Miocene landscape showed that major topographic features of the area had taken on their present form by mid-Tertiary, and that some of the features were formed in the Mesozoic. Since extrusion, plateau surfaces have lowered by 2 to 5 m/Ma, and most major streams incised by 5-18 m/Ma.

Young (1981) was able to show that stream incision in the upper Lachlan catchment has averaged around 4 m/Ma since the Early Miocene. This low rate contrasts with that of the mid-Macquarie River, which has incised 200 m since 12 Ma basalt flowed down the palaeo-Macquarie valley, an incision rate of 17 m/Ma.

Remains of very old basalt flows (~71 Ma, Late Cretaceous) preserved as hill caps in the rugged coastal zone west of Kempsey (Wellman and McDougall, 1974) suggest that although a few hundred metres of incision has occurred since extrusion, there has been very little or no uplift of the coastal zone in this area since 71 Ma. Apatite fission track data suggest kilometre-scale erosion (and hence similar uplift) close to the NSW coast after Tasman Sea breakup at 100-80 Ma (eg Dumitru *et al*. 1991, Persano *et al*. 2002). This sequence of events has been hotly debated by geomorphologists, based on the form of plateaux which appear to be downwarped close to the coast (eg Ollier and Pain 1997). The ages of the Kempsey flows suggest that if uplift and large scale erosion has occurred, it happened prior to 71 Ma.

FUTURE DATA AVAILABILITY

CRC LEME hopes to make the data publicly available via hard copy reports and spreadsheets of the data. However, we will not publish pers. comm. data that researchers do not wish to be published. The report will be of use both to igneous petrologists and geomorphologists. It is also possible that the data may be entered into the Geoscience Australia Ozchron database.

CONCLUSIONS

Ages of Cainozoic volcanics are being collated for use in a GIS along with other biophysical data to help with studies of landscape history. Knowledge of the rates at which landscape has developed will be important in determining areas over which the results of detailed investigations of regolith and salinity can be extended. In addition, connections between the rate of landscape development and the occurrence of dryland salinity will be studied.

REFERENCES

BISHOP P., YOUNG R.W. & MCDOUGALL I. 1985. Stream profile change and longterm landscape evolution: Early Miocene and modern rivers of the east Australian highland crest, central New South Wales, Australia. Journal of Geology **93**, 455-474.

DALRYMPLE G.B. 1979. Critical tables for conversion of K-Ar ages from old to new constants. Geology **7**, 558-560.

JOHNSON R.W. 1989. Intraplate Volcanism in Eastern Australia and New Zealand. Cambridge University Press, Cambridge.

JONES D.G. 1986. K-Ar isotopic dates, New South Wales. Geological Survey of NSW **Report 1986/237**.

MCKENZIE D.A., NOTT R.J. & BOLGER P.F. 1984. Radiometric age determinations. Geological Survey of Victoria **Report 74**.

OLLIER C.D. & PAIN C.F. 1997. Equating the basal unconformity with the palaeoplain: a model for passive margins. Geomorphology **19**, 1-15°

PERSANO C., STUART F.M., BISHOP P. & BARFOD D.N. 2002. Apatite (U-Th)/He age constraints on the development of the Great Escarpment on the southeastern Australian passive margin. Earth and Planetary Science Letters **200**, 79-90.

SPRY M., GIBSON D. & EGGLETON R. 1999. Tertiary evolution of the coastal lowlands and the Clyde River palaeovalley in southeast New South Wales. Australian Journal of Earth Sciences **46**, 173-180.

STEIGER R.H. & JAGER E. 1977. Subcommission on geochronology: Convention on the use of decay constants in geo- and cosmochronology. Earth and Planetary Science Letters **36**, 359-362.

SUTHERLAND F.L. 1983. Timing, trace and origin of basaltic migration in eastern Australia. Nature **305**, 123-126.

WELLMAN P. & MCDOUGALL I. 1974. Potassium-Argon ages of the Cainozoic volcanic rocks of New South Wales. Journal of the Geological Society of Australia **21**, 247-272.

YOUNG R.W. 1981. Denudational history of the south-central uplands of New South Wales. Australian Geographer **15**, 77-88.

YOUNG R.W. & MCDOUGALL I. 1993. Long-term landscape evolution: Early Miocene and modern rivers in southern New South Wales, Australia. Journal of Geology **101**, 35-49.

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