AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

Research staff from the Australian Geological Survey Organisation (AGSO) currently work within RSES almost exclusively on U-Pb SHRIMP geochronology. However, this capability has recently been significantly enhanced and diversified by the appointment of Dr Geoff Fraser as an Ar-Ar (and K-Ar) geochronologist for our organisation. Geoff is a PhD graduate of RSES and returns to Canberra after post-doctoral positions at the University of Adelaide, and the University of Calgary, Canada. As part of the Minerals Division within AGSO, he will be involved in a variety of regional projects.

AGSO research is based on the longstanding relationship with the Research School, in particular within the Geochronology and Isotope Geochemistry Group. The scientific outcomes address AGSO's role in Minerals Promotions under the National Geoscience Agreement (NGA), Petroleum Promotions, and Australian Geodynamics CRC (AGCRC). A selected range of research activities from these projects is described below.

The search for a high-quality zircon standard for SHRIMP Th-Pb-U geochronology

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Many geological studies are critically dependent on precise and accurate isotopic dating. As part of this process, micro-beam technology (including SHRIMP and ICP-MS applications) has over recent years become increasingly important in determining the age of events that have formed or modified rocks. SHRIMP Pb-U-Th zircon dating has been central to those studies. One of its many benefits is that it permits meaningful dating of selected parts of individual zircon grains, even when those grains represent more than one period of growth. A disadvantage of the technique is that SHRIMP produces Pb and U ions in very different proportions to the Pb/U of the target zircon. This complication is essentially irrelevant for the dating of old rocks (greater than 1000 Ma, or so), for which $^{207}Pb/^{206}Pb$ dating is employed. However, reduced levels of ^{207}Pb (due to the low abundance of its parent ^{235}U) generally make the $^{207}Pb/^{206}Pb$ method unsuitable for precise Phanerozoic and Neoproterozoic dating. The success of the $^{206}Pb/^{238}U$ method that is used in its place requires a means of precisely quantifying the enrichment (by about a factor of three) of Pb relative to U in the ion beam. This is achieved by interspersing analyses of a zircon of independently known age, measuring the difference between the expected and actual $^{206}Pb/^{238}U$, and applying the derived correction factor to the accompanying analyses of the unknowns. The reference zircon, known as the standard, is critical to the derivation of reliable $^{206}Pb/^{238}U$ ages.

Several different SHRIMP zircon standards have been used at RSES, as advances in technology and understanding have continued to refine the method. The production of progressively more precise data has allowed the question of standard homogeneity to be more rigorously addressed, and most of those standards have proved to be less than ideal in this regard. An ideal zircon standard should meet several criteria. 1. It must have been precisely and accurately dated independently of SHRIMP. 2. It must represent a single generation of zircon growth from sub-micron to inter-granular scales. 3. There must have been no post-crystallisation chemical or isotopic disturbance. 4. The standard should be easily collectible and abundant enough to last indefinitely. 5. Its quality should be sufficiently obvious that other laboratories will also choose to use it as a standard.

Our ongoing efforts to further refine SHRIMP Pb/U dating led last year to the identification of a very promising zircon standard in a high-level gabbroic diorite plug in the

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Lachlan Fold Belt, near Temora. One small, medium- to coarse-grained boulder of this rock produced ~10 ppm of isotopically homogeneous zircon. More than a dozen isotope-dilution thermal ionisation mass spectrometry (IDTIMS) analyses of that zircon by the Royal Ontario Museum, Canada, produced a consistently concordant age of 417 Ma for this zircon. The distinctive broad prismatic zoning and sector zoning of the crystals would make any country-rock xenocrysts easy to identify, but no evidence of any such inheritance has yet been found. Comparably fresh, large boulders of a more abundant, coarser-grained phase of the intrusion contain even more (~100 ppm) zircon, making it a particularly attractive candidate for widespread distribution. SHRIMP analyses, and concordant IDTIMS data reveal that the zircon in the coarser-grained rock is of indistinguishable age and isotopic integrity.

TEMORA has now become the AGSO standard of choice for the dating of Phanerozoic rocks. It is also currently being used in combination with the other standards, to derive the most appropriate conversion factors for the correlation of ages that have been calibrated against the various standards.

New phase of SHRIMP zircon geochronology at Broken Hill: towards robust stratigraphic and event timing

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Zircon U-Pb SHRIMP geochronology is a powerful means of elucidating geological ages and is most effective when integrated with unequivocal field constraints, and when the fundamental assumptions which are behind any isotopic dating methods can be geologically validated. In an attempt to better quantify the timing of the complex Palaeoproterozoic history of the Willyama Supergroup at Broken Hill, we have undertaken a new phase of U-Pb SHRIMP investigations. The objectives were to (a) benchmark our new age results to those of previous workers as well as to our own previous work in the Broken Hill Group; (b) evaluate and test the evidence for reported Archaean basement terrain; (c) date stratigraphic units in the upper parts of the Willyama Supergroup; (d) better constrain the timing of deformational events.

Our U-Pb SHRIMP work on zircons from layered paragneisses in the Redan Geophysical Zone near Farmcote was catalysed by earlier interpretations that these "trondhjemitic" gneisses represent an original ~2650 Ma protolith. Our work finds zircon provenance age signatures typical of almost all ca. 1700 Ma metasediments, whether in the Broken Hill Block or other Australian Palaeoproterozoic settings. This therefore suggests that the rocks are not Archaean basement, but were deposited about 1705-1710 Ma ago and are thus part of the Willyama Supergroup.

New SHRIMP work on the Alma Gneiss provides a magmatic age of 1704±3 Ma, and a minimum stratigraphic age for its host Thackaringa Group. This result is somewhat older than previously reported ages for the body, but is within error of our ages for other granitoids (1703±3 Ma, 1704±3 Ma) in a similar stratigraphic position near Farmcote. As the Thackaringa Group is no more than 1000-1500 metres thick and includes 1710-1700 Ma detrital zircons, part of the Alma Gneiss intrusion may well have been shallowly intruded, and akin to ~1700-1715 Ma felsic volcaniclastic and intrusive rocks in the Olary region, South Australia.

Potosi Gneiss lithotypes in the Parnell Formation (middle Broken Hill Group) and Hores Gneiss (upper Broken Hill Group) were initially interpreted as felsic volcaniclastic rocks with depositional ages of 1693±5 and 1689±5 Ma, respectively. We have now substantiated the Hores Gneiss age (1685±3 Ma) which, together with a new depositional age of 1691±3 Ma for tuffaceous metasediments in the lower Broken Hill Group, support the

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conclusion that the Broken Hill Group (excluding some amphibolite intrusions) is a coherent depositional package. Previous workers' suggestions that the Hores Gneiss comprises later intrusions (from 1690 Ma to 1640-1660 Ma old) and underwent high-grade metamorphism at 1640-1660 Ma are at variance with our data and the conclusions we draw here. Our age for the Rasp Ridge Gneiss (formerly 'hanging wall gneiss') of 1683±3 Ma indicates that this felsic magmatism postdates the middle Broken Hill Group, and was possibly coeval with the Hores Gneiss.

SHRIMP U-Pb work on Sundown Group rocks provides maximum depositional ages and provenance signatures using zircons in immature psammopelitic lithologies. Some sediments contain a small component of detrital zircons as young as ca. 1690-1700 Ma, but major sediment input is from terrains ca. 1790 Ma and 1820-1860 Ma old, as well as older Palaeoproterozoic and late Archaean sources. Tuffaceous siltstones in the middle Paragon Group, both in northern Broken Hill Block and Euriowie Inlier, record similar detrital zircon ages to the Sundown Group, but in addition they include pristine, unabraded zircons which date deposition at no older than 1656±5 Ma. Similar lithologies in the Dalnit Bore Metasediments (upper Paragon Group) provide a maximum depositional age of 1642±5 Ma.

Progress towards dating deformational events has been focussed on obtaining zircon ages for granitoid intrusions which bracket the deformations. This should enable us to constrain the D_2 event between 1597±3 Ma (age of pre-D_2 Purnamoota road Lf gneiss) and 1596±3 Ma (age of post-D_2 Cusin Creek pluton). The D_3 event can be no younger than a cross-cutting sheet of post-D_3 Mundi-Mundi granite (1591±5 Ma) whilst the pre- or syn-D_3 Cusin Creek pluton provides an older age limit (1596±3 Ma). Zircon rim overgrowths have ages at ~1600 Ma, confirming approximate synchroneity of high-grade metamorphic event(s) with deformations that were apparently closely spaced in time.

The improved geochronological framework for the Willyama Supergroup at Broken Hill invites closer comparison with Palaeoproterozoic sequences in northern Australia, such as the Mount Isa Inlier and McArthur Basin. The 1700-1710 Ma magmatic event, recognised now for the first time in Broken Hill, is considered an early phase of an intra-cratonic rift setting for the Willyama Supergroup, and may represent a tectonic analogue of this widespread magmatic event in the McArthur Basin.

Confirmation that the middle Paragon Group at Broken Hill is stratigraphically contemporaneous with mineralised sequences in northern Australia is an important outcome of this geochronological study. Specifically, there is now a definite age correlation basis for considering a refocus of some Broken Hill exploration efforts towards the Paragon Group. This consequence, along with other ramifications of our age determinations, provide a robust geological framework against which more advanced basin analysis and metallogenic models can be examined.

Geochronology and tectonic models relevant to Palaeoproterozoic high-potassium granites in the East Kimberley region, WA

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High-K granites extensively intruded all the Palaeoproterozoic terrains of northern Australia, and have generally been interpreted as the culmination of widespread intra-cratonic orogeny. SHRIMP U-Pb zircon geochronology has recently been undertaken in one of these terrains, the Lamboo Complex, which lies between the Kimberley and North Australian Cratons. The Lamboo Complex is divided into three terranes, referred to as the Western, Central, and Eastern zones, and is intruded by a variety of I-type granites and gabbros. High-K granites of the 1865–1850 Ma Paperbark supersuite are restricted to the Western zone.

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Tonalite sheets of the Dougalls suite, and unassigned leucogranite sheets intruded the Central zone at ca. 1850 Ma. The 1835–1805 Ma Sally Downs supersuite is composed of tonalite and high-K granite that mainly intruded the Central zone. However, high-K granites of the Sally Downs supersuite intruded all three zones from ca. 1820 Ma onwards, and mark the amalgamation of the terranes. The youngest granites in the complex, high-K granites of the 1805–1790 Ma San Sou suite, intrude the Eastern and Central zones. The temporal and spatial distribution of the granites is not easily reconciled with previous intra-cratonic tectonic models, but is consistent with tectonic processes similar to those operating presently.

Mapping the microstructures within zircon crystals by Synchrotron X-ray scattering and Raman microprobe.

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Zircon earns its place as perhaps the most important mineral in today's geochronological studies by its resistance to U-Pb isotopic resetting in many geological situations. However, the tresulting data are not always unambiguous because a variety of processes acting at the atomic scale can alter the concentrations of U and Pb within crystals. Uranium is not readily mobile because the atoms substitute at the Zr site in the zircon lattice. But Pb is rejected by the zircon lattice, and the Pb atoms that form from radioactive decay of parent uranium will be in sites damaged by the energy of the decay process, and thus potentially able to migrate within, or out of, the crystal should a pathway, a diffusion process, or a carrier be available. A variety of models exist that aim to account for isotope transport mechanisms, but understanding has been hampered by inability to image transport pathways at the atomic scale at which these processes operate.

This difficulty has now been overcome with the provision of access to the latest synchrotron X-ray source at ESRF, France. The synchrotron delivers X-rays approximately a trillion times stronger than conventional X-rays. Even when focussed to a microbeam 10 microns across, the beam is strong enough to penetrate and image the interior of a zircon crystal by both small-angle and wide-angle scattering of X-rays. The X-ray wavelength approximates the inter-atomic distances in crystals, so it directly images the crystallinity, radiation damage, and associated microstructure at the atomic scale at which Pb mobility occurs.

In a first attempt to obtain X-ray scattering maps of zircons, three days of beamtime provided by ESRF were used to scan the range of historical, current, and proposed SHRIMP standard crystals - SL3, SL13, AS3, QGNG, Temora, and a typical volcanic crystal from the Carboniferous Paterson Volcanics of NSW. Surprisingly, an extreme range in internal microstructure was found among what have in the past been regarded as "best available" reference zircons for geochronology. The high-uranium SL3 crystal is almost uniformly a local mixture of amorphous and crystalline domains, whereas the low-uranium SL13 crystal is almost uniformly perfectly crystalline, with little evidence of physical heterogeneities to account for the Pb isotope variations found within. The AS3, QGNG, and Paterson crystals all contain extreme local variations in crystallinity, with radiation damage and microstructural variability juxtaposed at the micro-scale. Juxtaposed crystalline states will create local atomic-scale stresses and elasticity contrasts within the lattice, so this information may lead us to document mechanisms that govern Pb mobility. An encouraging outcome for future SHRIMP dating is that the Temora zircon, proposed as the future dating standard, has been found to be uniformly crystalline throughout and contains few of these lattice heterogeneities.

This project will reach completion next year with conversion of the X-ray spot data into microstructural maps benchmarking the integrity of the zircon standards, and matching SHRIMP analysis of U-Pb isotope compositions in the same crystals. Corresponding maps of

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those crystals will be constructed from laser-induced Raman spectra as another measure of local lattice damage. It is known that the Raman spectrum of zircon is qualitatively degraded by radiation damage, and this can now be calibrated to definitive X-ray scattering measurements to enable quantitative mapping of crystallinity by the Raman technique. Preliminary Raman data has shown that the locations of lattice-damage (and therefore pathways for Pb migration) do not always follow the crystal zoning evident from light microscopy and cathodoluminescence — presumably because they are a secondary response to the atomic-scale physical structures imaged by the X-rays, rather than a direct result of the visible crystal zoning. Raman mapping of cystallinity could therefore become a more direct way of targeting pristine zircon zones for U-Pb dating.