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The present-day stress field of Australia: New release of the Australian Stress Map

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SUMMARY

The present-day stress field is important for a range of earth science disciplines including petroleum and geothermal geomechanics, mine safety, neotectonics and seismic hazard assessment. So far, many studies have been carried out to understand the state of stress in different parts of the world and the results reveal that the contemporary tectonic stress field can range from being uniform over large areas (100s-1000s of kilometres) to being highly varied over short distances (10s-100s of meters) due to interaction of different parameters. One of the most well-known examples of a heterogeneous stress pattern is observed in the Australian continent, which displays a wide range of stress orientations from province to province that, unlike all other major plates, are not aligned with absolute plate motion.

The Australian Stress Map (ASM) project was started in 1996 to compile a public data set of maximum horizontal present-day tectonic stress information to determine and understand the state of stress in the Australian crust. The early phases of the ASM revealed that plate boundary forces provide the first-order control on the present-day stress pattern. However, all models of the stress field have failed to replicate the stress pattern in Eastern, and particularly north-eastern, Australia. The ASM project commenced again in 2012 with a primary aim of building up the database in Eastern Australia, such as new hydrocarbon provinces, and to help better establish the controls on the Australian stress field at scales ranging from tectonic plate down to individual fields and wells. To date, we have interpreted more than 400 borehole image logs in coal seam gas, mineral and conventional petroleum wells. The results show that local sources of stress (i.e. second and third orders) play a key role in the stress pattern of Australia which is an important issue for geothermal and unconventional exploration and production.

Key words: Australian stress map, present-day stress, stress pattern of Australia, stress rotation

INTRODUCTION

The stress field in the Indo-Australian plate is unique amongst other major tectonic plates. Whilst all other major plates display first-order stress patterns that are parallel to absolute plate-motion, the Indo-Australian plate shows a highly varying regional stress pattern that has no correlation with Australia's N-NE absolute plate motion (Richardson 1992; Zoback 1992; Hillis et al. 1997, 2008; Hillis and Reynolds 2003; Reynolds et al. 2003). The present-day stress pattern of Australia is important in several disciplines including geodynamics (Richardson, 1992); neotectonics (Clark et al., 2012; Hillis et al., 2008); geomechanical characterization of petroleum basins (Tingay et al. 2005); earthquake hazard and mine safety (Sandiford et al. 2004); reservoir seismicity (Hillis 2000); and unconventional hydrocarbon and geothermal energy production (Bell, 2006).

The study of the Australian stress field has a long history, but the Australian Stress Map (ASM) project was started in 1996 to collect the maximum horizontal stress orientations (SHmax) from different stress indicators to build a freely available database in order to investigate causes and consequences of present-day stress pattern in the Australian lithosphere. The latest release of ASM, coupled with finite element modelling studies, highlighted that the plate boundary forces control the first-order SHmax pattern (Hillis and Reynolds, 2003; Reynolds et al., 2003). However, none of the constructed models could predict the present-day stress field in major basins in northern, central and north-eastern Australia. These basins contain the vast coal seam gas reserves critical to Australia's petroleum industry, and understanding of the stress state in these regions is critical for fracture stimulation and commercial extraction of gas from coal cleat systems (Flottman et al., 2013).

The ASM project was restarted in 2012 and aims to improve our understanding of the stress pattern in parts of the continent that previously had sparse or no published stress data, such as major coal seam gas basins of New South Weals and Queensland; and mineral (basement) wells of South Australia, conventional petroleum wells in offshore of Tasmania and couple of new wells in Northern Territory.

METHODS

The state of stress is commonly described by the stress tensor. In sedimentary basins, one of the principal stresses is considered vertical because the Earth's surface cannot transmit shear stresses (Bell, 1996). Hence, the stress tensor can be simplified to four components, the magnitudes of the vertical, maximum and minimum horizontal stresses, in addition to the orientation of the maximum horizontal stress (Bell, 1996; Tingay et al., 2005). Of these four components, the maximum horizontal stress orientation has received extensive attention because of its importance in understanding neotectonics and its usefulness for hydrocarbon production and in well design (Zoback, 2007; Bell, 1996). Hence, major projects, such as the ASM and the World Stress Map Project, have mainly focused on determining SHmax orientation. The ASM database contains several sources of information that each provides SHmax orientation from certain depths of lithosphere (0-40 km depth only). For example earthquake focal mechanism solutions, borehole breakouts and drilling induced tensile fractures observed in wellbores, engineering methods used in mines and tunnels (such as overcoring and hydraulic fracturing) and young (quaternary) geological indicators (Zoback, 1992; Heidbach et al., 2010).

THE 2015 ASM REALEASE

The latest version of the ASM (released in 2003) compiled 541 (A-E quality) indicators of horizontal stress orientation within the continent (Hillis and Reynolds, 2003). The 2015 ASM database (including the Australian continent and Papua New Guinea) contains more than 1000 A-C quality stress data. The majority of the data in the continent are from wellbore stress indicators (borehole breakouts and drilling induced tensile fractures); whilst stress indicators near plate boundaries (e.g. PNG) are dominated by earthquake focal mechanism solutions. Each stress indicator in the database has been ranked base on the World Stress Map quality ranking system from A to E quality. A-quality data indicate the SHmax orientation accurate to within ±15^o, B-quality to within ±15-20^o, C-quality to within ±20-25^o, D-quality to within ±25-40^o and E-quality indicates no reliable information (Heidbach et al., 2010).

The ASM project also has tried to provide information about the stress regimes for each of data point based on information availability. Up to now, most estimates of stress regime suggest strike-slip and reverse present-day tectonic regime through the continent, aside from in some passive margin sedimentary basins, which is quiet consistent with neotectonics studies (e.g. Clark et al., 2012; Hillis et al., 2008).

The scientific importance of 2015 release of the ASM is that both data quality and quantity has been improved significantly. Furthermore, local sources of stress (such as faults, fractures and density contrasts) are shown to play an important role in the stress pattern of many basins. In the previous version of the ASM, the majority of data were from conventional petroleum reservoirs (Figure 1). However, the 2015 release of the ASM has mainly focused on using recent unconventional, geothermal and mineral wells, in previously largely unstudied regions, to improve the database. We collected and interpreted borehole image logs in NSW (Clarence-Moreton, Gunnedah, Bowen-Surat, Gloucester and Sydney Basins) and Queensland (Surat, Bowen, Galilee and Cooper-Eromanga basins). In addition, thanks to the Australian Geophysical Observing System (AGOS) project, borehole image logs, which are routinely run in petroleum wells, have been used in mineral and basement wells in South Australia and Victoria. Hence, the majority of new data in SA and Victoria are from mineral and geothermal wells. We have also used the results of newly published research in Western Australia to further improve the stress map in the Perth and Carnarvon basins.

CONCLUSIONS

The new release of the ASM published herein has made major improvements both in quality and quantity of the Australian present-day stress field. Of particular importance is the release of new, and sometimes the first, detailed stress maps for several coal seam gas basins in NSW and QLD, in addition to the first studies of stress orientations in minerals wells across SA from image log analysis. The results show that previous models of the Australian stress pattern did not accurately predict SHmax orientation in many areas of eastern Australian, particularly in NSW and QLD. Furthermore, the new results show that plate boundary forces (first order of stress) are not the only major control on the Australian stress pattern, and that other local sources, such as fractures, faults and density contrast, are often a more dominant factor in local stress fields that are most relevant to petroleum, geothermal and minerals applications. Hence, the fundamental concept of the Australian stress field being primarily controlled by plate boundary forces needs to be re-evaluated or substantially refined. The key finding of new release is that the role of local sources of stress in many unconventional basins should be considered in any production and development of these fast growing future sources of Australian energy.

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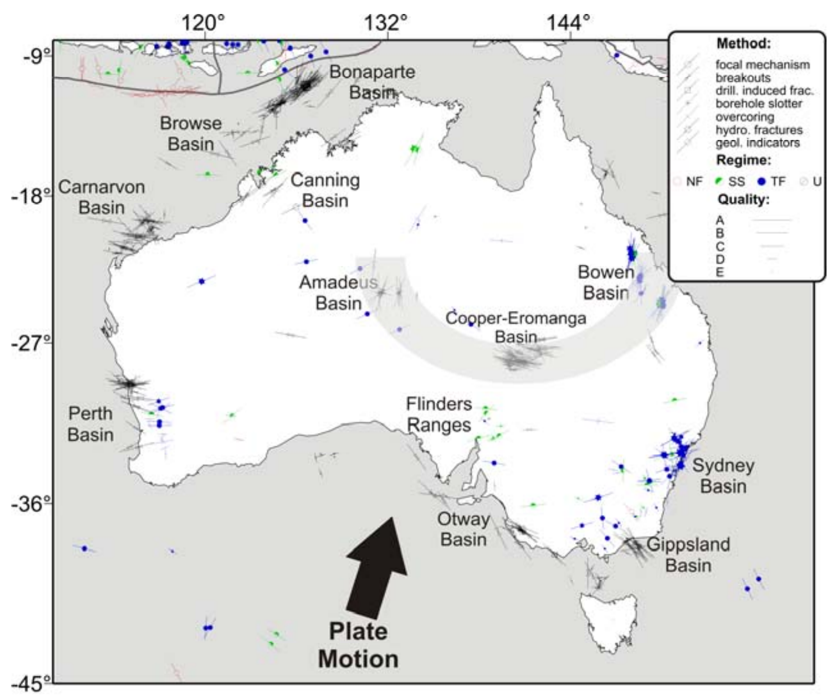

Figure 1: Previous version of the Australian present-day stress map (from Hillis and Reynolds 2003 and Heidbach et al., 2010). Symbols and different colours indicate the method of measurement (circles are focal mechanism solutions, inward-facing arrows are breakouts) and the stress regime (NF=normal faulting stress regime; SS=strike–slip faulting stress regime; TF=thrust faulting stress regime; black=undefined stress regime). Length of the lines indicates quality of data. The orientations clearly demonstrate the variability (compare with the plate motion) particularly in northeast Australia where patterns show a horseshoe shape trend. The majority of the data for Australia are those which interpreted by drilling-related stress indicators from borehole image and caliper logs in conventional petroleum wells. Furthermore, Absence of data outside of mature and conventional petroleum provinces is clear.