8 MINING-INDUCED SEISMICITY

8.1 SEISMIC ACTIVITY

Issue:

The concern was raised that the excavation of the proposed open pit could cause de-stressing-induced seismic events (i.e. earthquakes) in the vicinity of the proposed mine.

The potential risks this poses to the operations and human safety was questioned.

Submissions: 2 and 137

Response:

The excavation of the proposed open pit would result in some low-magnitude mining-induced seismicity. It is unlikely these events would be noticed by members of the public or the on-site workforce and there would be little, if any, damage to the mine or associated infrastructure. The residual impact of such events is considered 'low'.

In order to put the risks associated with mining-induced seismicity into further context, the risk of a greater-magnitude event has also been considered in accordance with the risk assessment methodology outlined in Chapter 26 of the Draft EIS. The risk of a large-magnitude event is considered low, resulting from a rare frequency and moderate consequence. This is described further in the following sections.

Context

Earthquakes are relatively common in South Australia. Since the operations at Olympic Dam commenced (in 1988), the Geoscience Australia seismic monitoring network has recorded around 1,420 earthquakes in South Australia (Geoscience Australia 2010a and b). Most were centred on the Flinders Ranges, with others occurred at various locations throughout the state (see Figure 8.1 of the Supplementary EIS). These earthquakes varied in magnitude from 0.2 to 5.4 on the Richter scale, with a mean magnitude of around 2.2 and a median magnitude of 2.0. In the three months to June 2010, the South Australian earthquake monitoring network recorded 20 earthquakes (see Table 8.1 of the Supplementary EIS) varying in magnitude from 0.7 to 5.0 (PIRSA 2010).

The Richter scale, used to quantify the magnitude of an earthquake, compares the maximum heights of seismic waves at a distance of 100 km from the epicentre. For every 0.1 increase in Richter scale magnitude, there is a three-fold increase in the energy released by an earthquake. For example, a magnitude 2.0 earthquake releases 30 times more energy than a magnitude 1.0 earthquake.

The effects of an earthquake depend on many factors, including distance from the epicentre and regional and local ground conditions. The typical impacts of earthquakes of various magnitudes at locations near the epicentre are summarised in Table 8.2 of the Supplementary EIS.

There have been about 10 large earthquakes (magnitude 6.0 or greater) in Australia since 1900, five of which have resulted in surface rupturing (see Table 8.3).

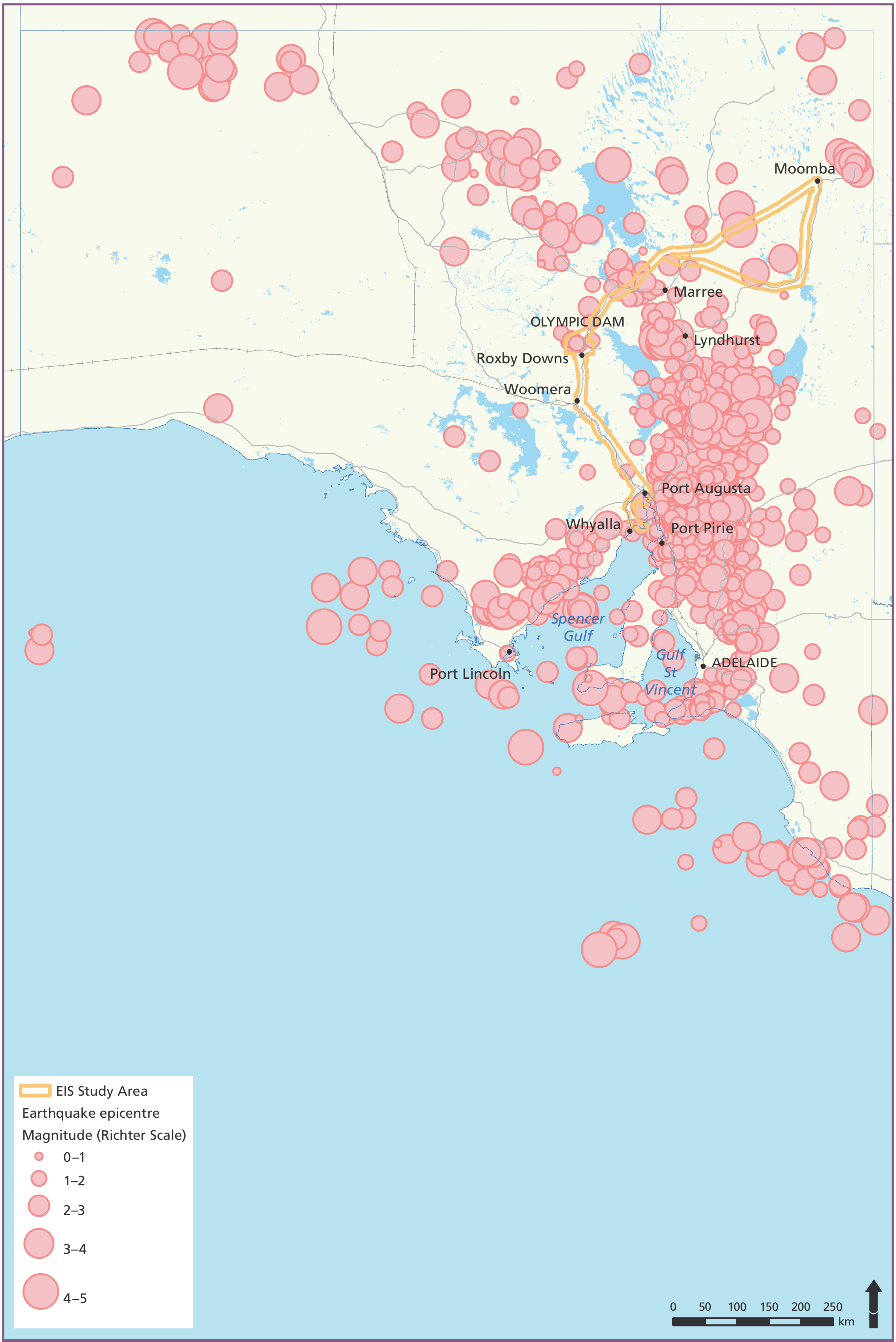

Figure 8.1 Earthquakes in South Australia since 1988

Table 8.1 Recent earthquakes in South Australia

Date in 2010	Time (UTC)	Latitude	Longitude	Location	Magnitude
22 June	20:41	–32.643°	138.509°	13 km W of Orroroo	3.0
5 June	21:47	–33.593°	136.710°	22 km NE of Cleve	5
30 May	07:11	–33.126°	138.856°	15 km S of Peterborough	1.9
30 May	12:14	–35.248°	139.005°	10 km E of Strathalbyn	1.3
28 May	10:06	–33.071°	137.448°	13 km W of Whyalla	2.5
27 May	11:08	–33.963°	139.157°	15 km W of Morgan	2.8
27 May	12:52	–33.963°	139.512°	15 km W of Morgan	2
21 May	17:44	–32.892°	138.382°	47 km NE of Port Pirie	1.5
17 May	16:21	–35.367°	138.698°	6 km E of Mount Compass	0.9
16 May	15:59	–35.866°	136.696°	88 km SW of Kingscote	1.7
14 May	15:58	–34.369°	139.540°	7 km SW of Blanchetown	0.9
14 May	9:42	–32.647°	138.305°	51 km SE of Port Augusta	2.3
13 May	6:21	–34.390°	135.563°	8 km SW of Blanchetown	0.7
10 May	11:32	–34.066°	135.951°	29 km NE of Cummins	2.6
7 May	15:42	–35.111°	139.169°	9 km W of Murray Bridge	0.8
6 May	10:21	–34.091°	135.718°	19 km N of Cummins	1.8
3 May	13:30	–33.001°	138.125°	22 km NE of Port Pirie	1.4
26 Apr	22:04	–37.578°	139.185°	68 km SW of Robe	2.4
26 Apr	22:00	–35.506°	139.212°	38 km E of Goolwa	0.8
24 Apr	20:35	–32.860°	138.185°	15 km W of Booleroo Centre	1.6

Table 8.2 Typical impacts of various magnitude earthquakes

Magnitude	Description of impacts
Less than 3.4	Usually felt by only a few people near the epicentre
3.5–4.2	Felt by people who are indoors and some outdoors; vibrations similar to a passing truck
4.3–4.8	Felt by many people; windows rattle, dishes disturbed, standing cars rock
4.9–5.4	Felt by everyone; dishes fall from shelves and doors swing, unstable objects overturn
5.5–6.1	Some damage to buildings; plaster cracks, bricks fall, chimneys damaged
6.2–6.9	Much building damage; houses move on their foundations, chimneys fall, furniture moves
7.0–7.3	Serious damage to buildings; bridges twist, walls fracture, many masonry buildings collapse
7.4–7.9	Causes great damage; most buildings collapse
Greater than 8.0	Causes extensive damage; waves seen on the ground surface, objects thrown into the air

Source: Geoscience Australia

Table 8.3 Recent large surface-rupturing earthquakes in Australia

Date	Location	Magnitude	Surface rupture length	Displacement
October 1968	Meckering (WA)	6.7 +/– 0.1	35 km	2 m
March 1970	Calingiri (WA)	5.8 +/– 0.2	2 km	0.1 m
June 1979	Cadoux (WA)	6.0 +/– 0.1	10 km	1 m
March 1986	Marryat Creek (SA)	5.8 +/– 0.1	13 km	0.6 m
January 1988	Tennant Creek (NT)	6.7 (largest event)	35 km	2 m

Human-induced seismicity

A seismic event typically refers to a tremor associated with an episode of damage to a rock mass caused by induced stress. The energy released seismically is a very small proportion of the total energy dissipated due to rock mass damage. A seismic event is over once the rock mass has completed its transition from one stress condition to another (i.e. from a less broken state to a more broken state) and vibrations have ceased. Seismic events are almost always caused solely by concentrations of stress in excess of the strength of the rock or discontinuities in the rock, and these excess concentrations of stress are due to this stress redistribution. Human-induced seismicity occurs when activities undertaken by humans change the local rock stress regime. The four most significant potential pathways for human-induced seismicity are:

- injection-induced seismicity (for the recovery of oil and/or gas)
- reservoir-induced seismicity (the filling of water storage reservoirs)
- mining- and quarrying-induced seismicity (from both underground and open-pit mining)
- seismicity induced by nuclear explosions (particularly underground testing).

Reservoir-induced seismicity caused through the filling of water storage dams has historically resulted in the greatest potential to induce damaging earthquakes, with several recorded earthquakes of greater than magnitude 6.0, including a magnitude 6.3 earthquake in India which is considered the greatest magnitude human-induced earthquake to date (Cypser 1996; McCue 2010). In general, however, human-induced seismicity usually occurs at low magnitudes and rarely causes damage (Cypser 1996).

When an excavation is formed in rock, such as during mining activities, the pre-existing stresses in the rock are redistributed. The redistribution of load around a mined excavation always results in some damage to the rock mass surrounding the excavation, as there is less rock to sustain the tectonic and gravity load, resulting in some of the nearby rock becoming over-stressed. This localised damage to the rock mass is an unavoidable consequence of mining and occurs in all mines. In mining literature, the stress condition that exists after excavations are formed is called the mining-induced stress state. Sometimes, when damage due to mining-induced stress occurs, the damage is heard or detected with equipment that measures vibrations. In this case it is called a seismic event, or more commonly in technical literature, mining-induced seismicity.

A relationship between mining activity and seismicity has been inferred in mining operations around the world. It is estimated that around 25% of all earthquakes recorded by the British Geological Survey may be related to coal mining (Redmayne 1988) and that most of the seismic events recorded by the Geological Survey of South Africa in the former Transvaal and Orange Free State regions may be the result of deep mining operations in the region (Fernandez 1988). Further investigations in the British coalfields have indicated that recorded seismicity varies in frequency in parallel with mine production schedules, with seismicity decreasing during holiday periods and upon mine closure (Redmayne 1988).

Mining-induced seismicity for the proposed open pit mine

In order to assess the potential of the proposed open pit development to influence stability in the existing underground mine workings at Olympic Dam, a 3D Finite Element Model of the proposed and existing operations was developed to simulate rock stress and deformation changes induced by the proposed open pit (See Appendix D1 of the Supplementary EIS). This model took into account the measured virgin stress conditions, the presence of geological structures including Mashers Fault, variations in properties between geological domains, the sequential and iterative extraction of rock from the proposed open pit and existing underground mining operations, and the effects of groundwater. The developed model was subsequently calibrated against measurements of seismicity and observations of rock mass damage at the existing underground mining operation (see Appendix D1 of the Supplementary EIS for further details of the model development and outputs). The purpose of the model was to estimate the extent and nature of mining-induced damage and deformation, including seismicity, specifically focused on the potential impacts to the existing underground workings.

Figure 8.2 of the Supplementary EIS shows the correlation between dissipated plastic energy (DPE) and event probability for all rock types associated with the proposed expansion. The data points represent measured seismic events within a certain magnitude and DPE range, effectively providing a calibration of the model. The use of the ‘All Events’ probability curve relationship in the model provides a conservative estimate of the seismicity in the Mashers Fault zone as the rock there is much softer and weaker than the average for the whole rock mass. The probability equates to the chance of having an event at the indicated magnitude within a 25 m radius of the test location during the time period of the model step. Figure 8.3 shows the modelled DPE at Year 40 on a section through the Mashers Fault as an example of a typical year’s worth of event potential. The results above the ore body unconformity should be ignored, as there is currently no seismicity measured in these areas, as the rock material is too soft to generate detectable events.

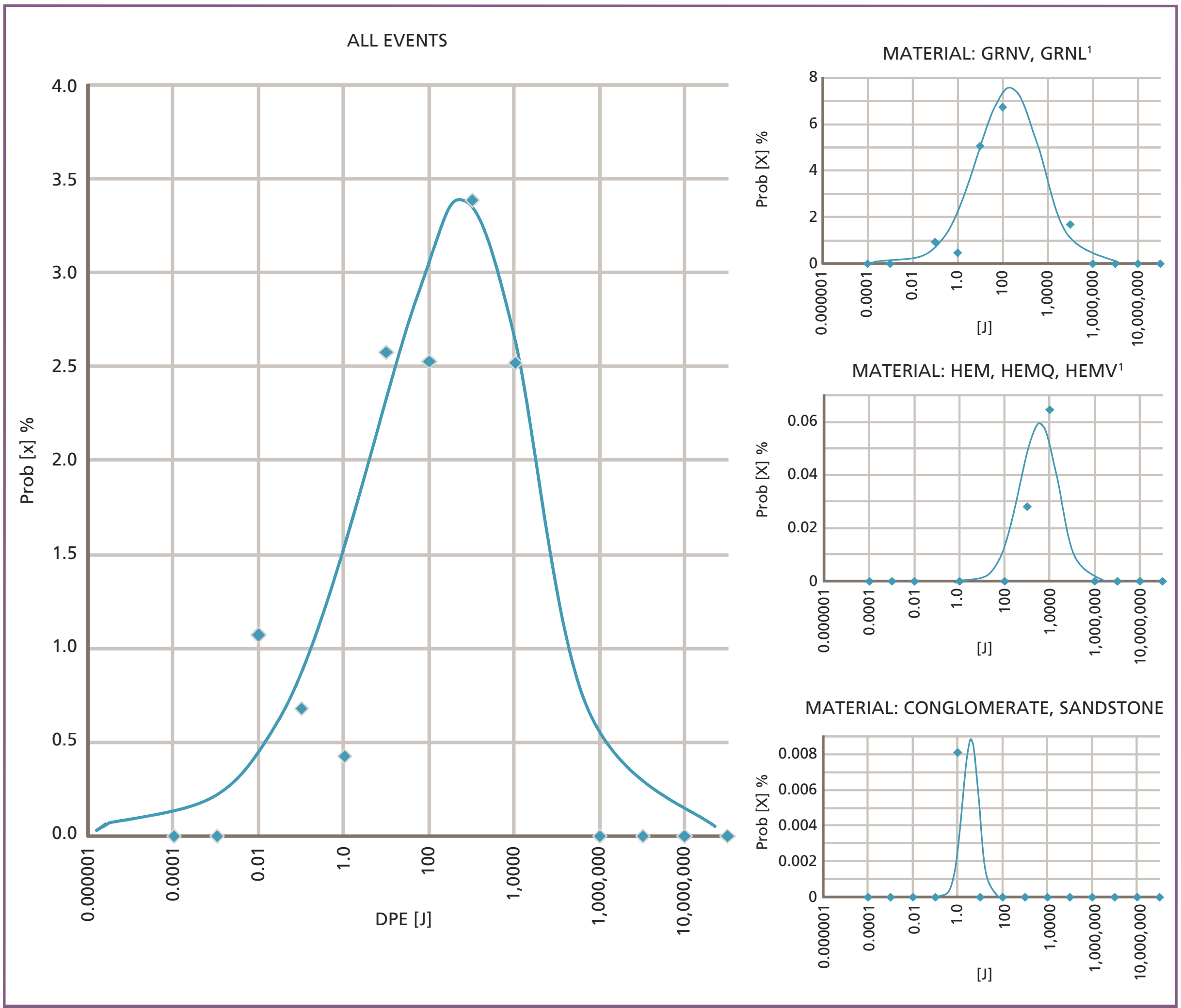

Figure 8.2 Correlation between dissipated plastic energy (DPE) and event probability for all Olympic Dam rock types

[1] Rock unit descriptions are provided in Appendix K5 of the Draft EIS.

The results of the modelling were summarised (See Appendix D1 of the Supplementary EIS) as follows:

- The model was able to confirm that induced seismicity as a result of the proposed open pit is expected to be similar to the seismicity that has occurred in the past.
- The seismogenic zone (limits of induced seismicity) can be interpreted to grow proportionally in increments matched to the changes in the shape and size of the pit. This encourages the release of energy in smaller, more frequent increments and is fundamental to the principle of management of mining-induced seismicity. For a large seismic event to occur, the mine would need to isolate a very large area of Mashers Fault with very high confinement, generate large amounts of elastic strain and then cause an instantaneous release of that stored energy by inducing an increment of damage that allowed that energy to be released. This scenario is clearly not evident and there is no indication of significant energy releases due to the continuous release of DPE in regular increments during progressive mining. Such events are possible, though unlikely, and there is considered to be no special risk factor for the proposed pit compared to other pits.
- It is clear that the damage to Mashers Fault does not occur in a small number of very large steps, as would be needed for a regional-scale seismic event (greater than magnitude 4) to occur due to the pit mining. Rather, the energy is released incrementally in approximately similar amounts in each step. Based on experience, this is considered good practice for managing mining-induced interaction with fault zones for seismic outcomes.

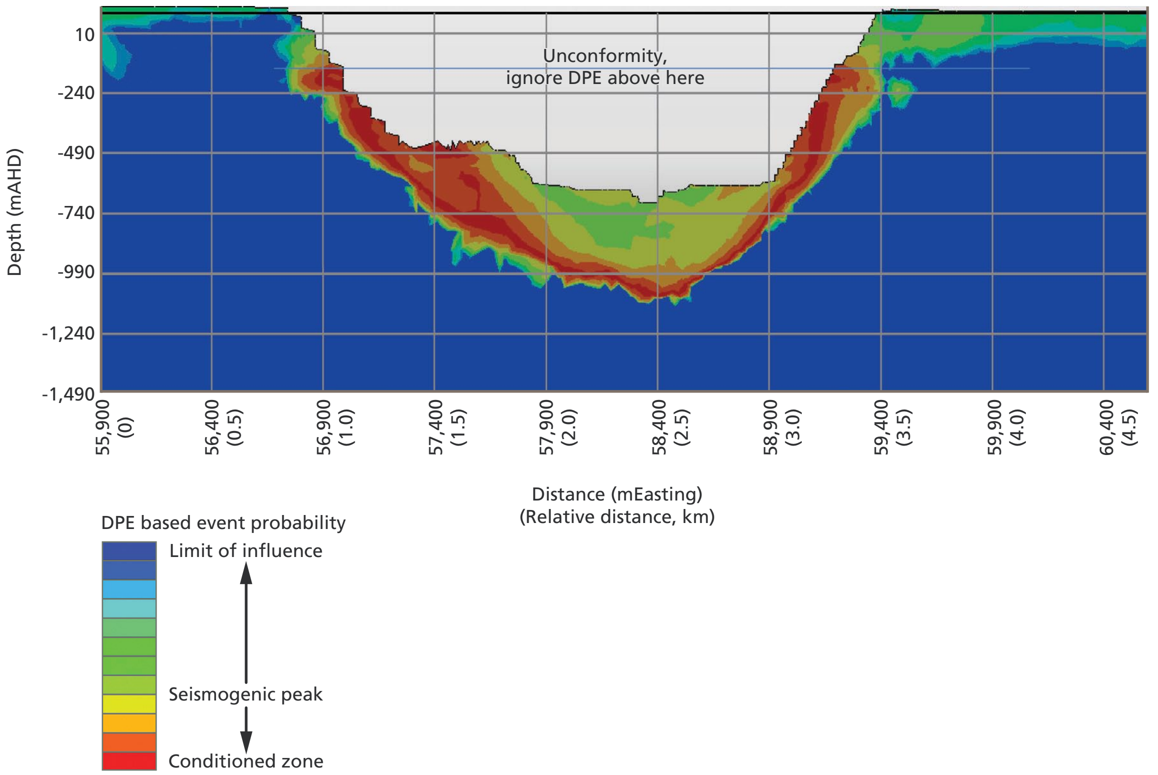

Figure 8.3 Dissipated Plastic Energy (DPE) event probability for the Year 40 open pit

Potential impacts and risk of mining-induced seismicity

As discussed earlier in this response, human-induced seismicity usually occurs at low magnitudes. The consequences of a magnitude 5.4 earthquake, the largest recorded mining-induced earthquake, would not normally be great for pit slopes. In Chile, large (non-human-induced) earthquakes are experienced in deep pits such as Chuquicamata and have not been associated with slope failures.

It is anticipated, based on the modelling undertaken, that the proposed open pit mine would result in some local changes to rock stresses and it is likely that, based on the literature reviewed and the experience of the seismologists commissioned to investigate this issue, that this would result in some induced seismicity. This seismicity is expected to be very localised and small in magnitude, unlikely to exceed magnitude 4 even using worst-case modelling assumptions (see above for details). The potential consequences of a magnitude 4 earthquake would be limited to a temporary (five to 10 second) increase in vibration, similar in magnitude to that presented by a passing truck, with little if any damage, even to local facilities and structures. As a result, the residual impact would be low.

To place the risk of a large mining-induced seismic event in the context of the criteria used in the Draft EIS (refer Section 26.2 and Appendix C of the Draft EIS for details), it is considered that the risk rating for a greater than magnitude 5.7 event resulting in surface faulting and infrastructure damage is ‘low’ (representing a ‘rare’ likelihood and a ‘moderate’ consequence).

Issue:

The use in the Draft EIS of a probability acceptance criterion for seismic events of 10% in 50 years for major components of the project (including the desalination plant, open pit and process plant) was questioned, given that the expanded operation is likely to continue beyond a 50-year timeframe.

Submission: 2

Response:

The inclusion of this information in the Draft EIS was to provide an indication of the likely acceleration coefficient in the areas where project infrastructure is proposed, rather than to suggest that infrastructure associated with the expanded operation would be designed to these earthquake probability criteria.

Section 8.4.1 of the Draft EIS presented an overview of earthquakes in a South Australian context. Part of this high-level analysis included reference to the Earthquake Hazard Map of Australia (McCue et al. 1993) to determine acceleration coefficients at the locations of proposed expanded operation infrastructure. The Earthquake Hazard Map of Australia was used as the basis for a Standards Australia committee review in Australia for the Australian Building Code AS1170.4 – 1993 Minimum Design Loads on Structures – Earthquake Loads (since superseded by AS1170.4 – 2007 Structural Design Actions – Earthquake Actions in Australia). The Earthquake Hazard Map of Australia contoured the peak ground acceleration, velocity and Modified Mercalli (MM) intensity for a 1-in-475-year event, equivalent to a 10% chance of the acceleration coefficient being exceeded in 50 years.

As indicated in Section 8.4.1 of the Draft EIS, all infrastructure would be designed to meet or exceed the relevant codes and standards with regards to structural integrity, including integrity associated with earthquake loadings. In addition, the proposed tailings storage facility (TSF) has been designed to meet the ANCOLD stability requirements for a 1-in-10,000-year earthquake event loading (see Section 5.3 of the Supplementary EIS for further information regarding stability and factors of safety for the proposed TSF).