25-29th September 2016
Montpellier, France
CORUM CONFERENCE CENTER
43rd IAH congress

Abstract n°2137

Conceptual models of risks to shallow waters associated with underground mining through geological fault structures

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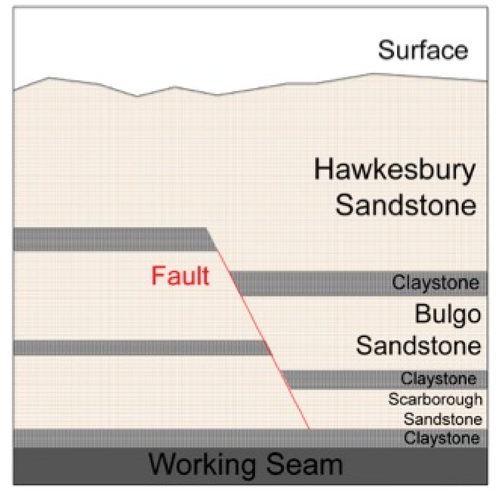
Water risks associated with mining through geological faults have received little attention compared to geomechanical and safety risks. Longwall coal mines in the Sydney Basin, Australia, work to avoid consequences of impacting water supply dams, creeks, peat swamps and shallow aquifers. Various models for geological faults in the near-field and far-field of mining operations were considered to inform the design of strategic monitoring and adaptive management.

2 Background



Low permeability strata in the constrained (unfractured) zone above a longwall mines can provide an effective barrier to help protect shallow waters (David et al., 2015), if there are no hydraulically active faults. However 3 types of faults (penetrating, surface fault, mine level fault) occur under various conditions. No "high level" consequence mine inflow events were reported in the past 25 years in Southern Coalfields, indicating that faults tend to be more typically barriers than conduits to flow (Tonkin and Timms, 2015). Elsewhere, reactivation of faults has been documented near coal mines including at sites in Europe, North America, South America, Africa and Asia (Donnelly, 2006).

Consequence levels for mining *AGM (2007); Galvin (2016)*

Level	For people	For equipment	For production	For environment
5	Fatality/permanent disability	>$500k damage	>$500k loss	Licence revoked
4	Major injury	$100-500K damage	$100-500K loss	Prosecution
3	Av. Lost time injury	$50-100K damage	$50-100K loss	Infringement notice
2	Minor injury	$5-50k damage	$5-50k loss	Reportable non-compliance
1	Medical treatment or less	<$5k damage	<$5k loss	Incident – no regulation

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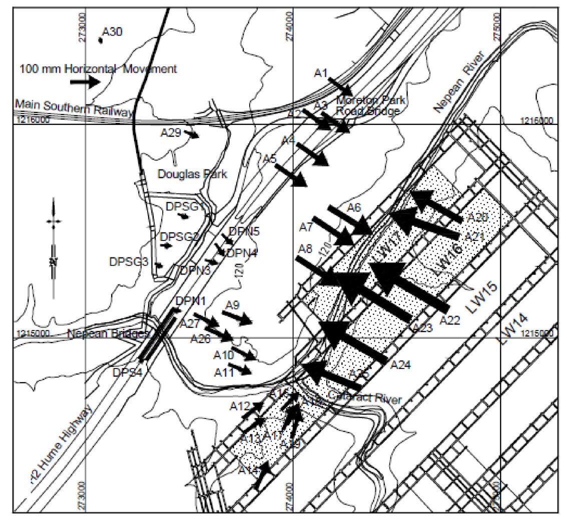
With thanks to Dr C Zhang, C Tonkin, H Tadokoro and K David

3 Ground movement – Tower longwall mine

Total horizontal movements due to 2 longwalls



*AOD - angle of draw defines area of surface subsidence

Monitoring technology of far-field ground movements (that could open conduits to flow) are improving including:
eg. GPS stations – total movement from start of one longwall to 3 months after an adjacent longwall

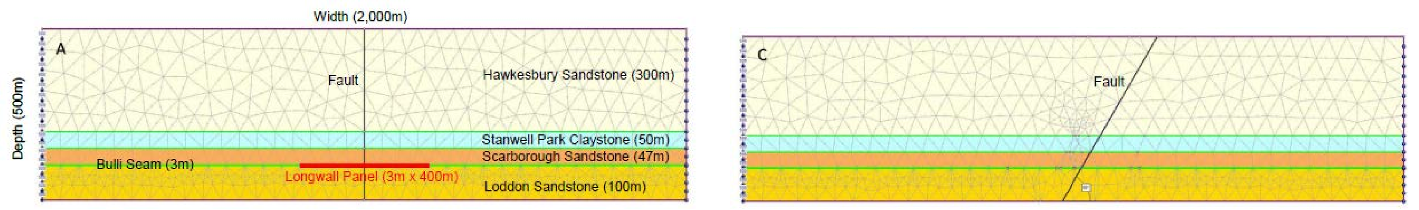
Movement of monitoring stations was

- ***up to 65 mm at 680 m from goaf*** edge, AOD* 56°
- up to 70 mm at 450 m from goaf edge, AOD 45°

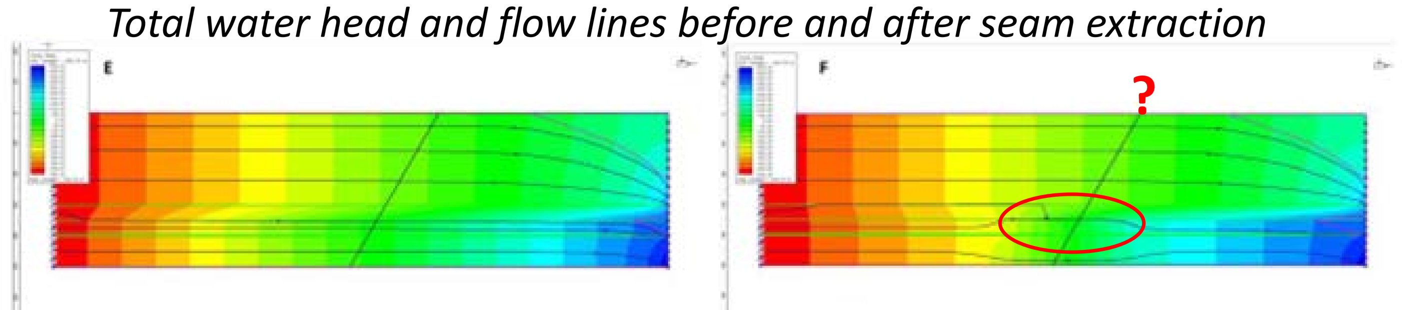
Possible mechanisms: horizontal stress effects, ***activation of sub-horizontal structures,*** valley notch effect, massive strata cantilevering Hebblewhite et al. (2000)

4 Models and likelihood of fault impacts for shallow waters

Base models for a penetrating fault and oblique fault



Total water head and flow lines before and after seam extraction



Fault scenarios are being explored using RS2 v9, 2D FEM (Rocscience Inc.), a geomechanical model for simulating stresses from extraction, and also groundwater conditions.

Likelihood
5 Almost certain, 4 Likely
3 Occasional, 2 Unlikely
1 Rare

Fault type	Closed fault	Partially open	Open fault
Penetrating	2	4 – 5	5
Surface	2	3 – 4	4 - 5
Mine level	1	2	2

Risk = likelihood x consequences

Conditions that multiply the likelihood of impacts include the following:

- Sediment or peat cover thin
- Distance to mine goaf proximal
- Total tonnage extracted large
- Cover depth to basement limited
- Continuity or density of faulting high
- Fault orientation oblique
- Stresses favourable eg tension
- Displacement connects aquifers
- Fault clay fill & weathering minimal
- Fracture zone damage significant & wide

5 Lessons for adaptive management and monitoring

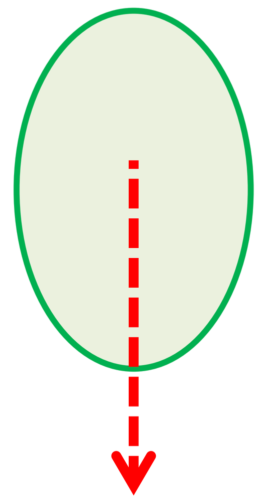
Options for adaptive management and mine design to reduce surface subsidence, particularly related to geological structures, include the following:

1. Mining geometry – panel width, mining height, cover depth eg. sub-critical design
2. Changing distribution & length of panels
3. Orientation of panels to principle stresses
4. Splitting panels to avoid sensitive features
5. Increasing distance of panels from dam wall
6. Backfill – emplacement of coal rejects into mine voids
7. Barrier pillars – coal left in place, reduced resource extraction (80% → 50% → 35%)

Avoiding ***long term consequences*** for shallow aquifers, creeks and peat swamps depends on on-going monitoring and site investigation of fault zone hydrogeology. eg. Bense et al. (2013)

Basic to advanced strategic monitoring, depending on risk level:

- High frequency pore pressure monitoring, isotope tracer s
- Moisture monitoring within thin peat swamps



Monitoring along fault strike, beyond the AOD

Ground movement in ***near-field and far-field*** can occur under some conditions along strike of geological faults, outside the angle of draw and >500 m from goaf

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A risk based approach for adaptive management can be advanced based on monitoring and modeling of potential impacts of faults on shallow waters. Under favorable conditions, faults that are restricted to mine levels are a low risk to shallow waters. However, in high risk situations, mitigating negative environmental consequences is particularly important.

7 References

Australian Geomechanics Society, (2007); **Bense et al.** (2013) *Earth-Science Reviews* 127: 171–192
David, K., Timms, W., Baker, A.(2015). Direct stable isotope porewater equilibration and identification of groundwater processes in heterogeneous sedimentary rock. *Science of the Total Environment*. 538, 1010 – 1023.; **Donnelly L.J**, (2006). A review of coal mining induced fault reactivation in Great Britain. *Quarterly Journal of Engineering Geology and Hydrogeology*, 39, 5-50; **Galvin**, J (2016) Ground Engineering – Principles and Practices for Underground Coal Mining, Springer; **Hebblewhite**, et al. (2000). Regional horizontal surface displacements due to mining beneath severe surface topography (pp. 149–157). Paper presented at the 19th international conference ground control in mining, Morgantown, WV, West Virginia University. **Tonkin, C, Timms, W.** (2015) Geological structures and fault-infill in the Southern Coalfields and implications for groundwater flow. *Journal of Research Projects Review*, 2015:49-58, Mining Education Australia.