The 19th International Mining Congress and Fair of Turkey, IMCET2005, Izmir, Turkey, June 09-12, 2005

Status and Prospects of Underground Thick Coal Seam Mining Methods

B K Hebblewhite
School of Mining Engineering, The University of New South Wales, Sydney, Australia

ABSTRACT: Australia has very large thick seam coal resources. As a result, there has been ongoing research conducted by UNSW and others into suitable mining methods that are capable of safe, efficient and productive resource recovery. The significant production improvements achieved in the Chinese coal mining industry over the last decade, as a result of development and application of the LTCC method, has prompted Australian mines to examine the method and its potential, for Australian application. This paper presents the key issues and latest findings from recent thick seam mining research conducted by UNSW into various mining methods, but particularly, the Chinese LTCC method. In respect to LTCC, geotechnical factors such as coal strength and rock mass characteristics are considered with respect to caving potential and face support performance. The caving and coal clearance simulation/optimization research includes evaluation of a range of front and rear conveyor capacities relative to different caving strategies, as well as alternate panel conveying options.

1 INTRODUCTION

There has been considerable interest in underground thick seam raining methods in Australia for many decades. As outlined later in this paper, Australia has significant reserves of thick coal seams that require the application of alternative mining methods - beyond the conventional bord and pillar or standard longwall systems. The incentive for identifying or developing new methods for underground thick seam mining is primarily optimising resource recovery. However, the Australian coal industry is an export-dominated industry where high productivity, sustainable financial viability and the highest safety standards are paramount. As such, the Australian requirement is for appropriate methods which meet the Australian safety and productivity/financial performance criteria, or preferably improve on them, at the same time as achieving improved resource recovery.

As a point of definition, the term thick seam has been applied to any minable seam thickness greater than the reach of existing development and longwall systems. In the 1980s and 1990s, this was interpreted as 4.0m. However, with higher reach continuous miners and longwall systems, an arbitrary figure of 4.5m has been adopted for all recent studies.

Earlier studies by UNSW and others (Hebblewhite, 1999 & Hebblewhite et al., 2002) reviewed the Australian opportunities and available methods and technologies for underground thick seam methods. Arising from this review, four generic methods were identified as having thick seam potential. These were:

- extended height single pass longwall (SPL)
- multi-slice longwall (MSL)
- hydraulic mining (HM)
- caving longwall systems (CL), including longwall top coal caving (LTCC).

The option of extending the height of a conventional single pass longwall was considered to have limited possibilities. It was apparent that technology was already gradually increasing both shearer and support heights from 4m to 4.5m and now up to 5m and above (Hamilton, 1999). However, limitations such as equipment size, weight and stability, plus face conditions were considered to limit the application of this method to no more than 6m height, for many years to come. The method is certainly considered to have potential in the 4.5m - 6.0m height range, however. A summary of latest developments in SPL is included below.

Multi-slice longwall was also reviewed in detail, with consideration of experiences from both Europe and China with this method. The potential to apply modern paste fill technologies for septum formation and stabilisation was investigated (Palarski, 1999, Bassier & Mez, 1999). However, through a risk assessnv .1 process, some of the other issues such as mining under goaf areas (water and gas hazards), and general stability concerns, ruled this method out as a viable option for Australia at the present time, quite apart from the very limited gains in productivity anticipated.

Hydraulic mining, as practised in New Zealand and elsewhere previously, was investigated. It was found to be a method with a significant potential in a limited range of suitable mining conditions. It offered significant financial benefits, but limited large scale production potential. It was therefore considered to be suitable as a "niche application" method, but not a universally applicable option. A brief review of this method is also included below.

This then left the range of longwall caving options. Evaluation of different European and early Chinese experiences with the original "soutirage" mining concepts and equipment showed promise, but performances were below the level required to be viable in Australia, not to mention concerns over issues such as dust and spontaneous combustion. The main focus of this paper is on the LTCC method and some of the factors that must be considered when assessing the potential application of LTCC.

Prior to discussing the actual mining methods, it is considered appropriate to review the Australian thick seam resource database in order to gain an appreciation for the extent of these resources.

2 AUSTRALIAN THICK SEAM RESERVES

Table 1 summarises the extent of thick seam reserves in Australia - both in terms of measured reserves and measured plus indicated (Hebblewhite et al., 2002). These figures confirm that there are at least 6.4 billion tonnes of minable underground thick seam reserves. Some significant features of these minable reserves are:

- 86% are in seam thicknesses between 4.5m and 9m, with 51% in the 6m-9m range.
- 84% are in seams with a dip of less than 15°
- 76% are less than 300m depth.

The above parameters confirm that the majority of thick seam reserves are in the 6m - 9m range, beyond the scope of Single Pass Longwall, but eminently suitable for the LTCC method. Furthermore, the seam dips and depths are also within the range of current LTCC technology.

Table 1. Australian thick seam reserves *(after Hebblewhite et al., 2002)*

AUSTRALIA		Number of Sites	(Measured) Resources (million tonnes)	% Measured Resources (%)	Ind & Meas Resources (million tonnes)	% Ind & Meas Resources (%)
Seam Thickness	4.5m - 6.0m	29	2249	34.8	7425	42.2
	6.0m - 9.0m	33	3310	51.2	8397	47.8
	> 9.0m	9	597	9.2	1113	6.3
	No Info	2	310	4.8	650	3.7
	Total	**73**	**6466**	**100.0**	**17565**	**100.0**
Seam Dip	< 5.0 deg	43	3173	49.1	11684	66.4
	5.0 deg - 15 deg	21	2256	34.9	3698	21.0
	> 15 deg	9	1037	16.0	2203	12.5
	Total	**73**	**6466**	**100.0**	**17565**	**100.0**
Seam Depth	< 150m	28	3312	51.2	6303	35.8
	150m - 300m	23	1594	24.7	5383	30.6
	> 300m	19	1508	23.3	5698	32.4
	No Info	3	52	0.8	201	1.1
	Total	**73**	**6466**	**100.0**	**17565**	**100.0**

3 SINGLE PASS LONGWALL

Current high capacity single pass longwall practice, worldwide, is restricted to height ranges of 4.5m to 5.5m. Tables 2 and 3 summarise the known, high capacity longwall faces operating around the world at the present time in this height range. It is significant to note that although a number of faces have the capacity to operate at 5.5m and above, they are typically working at lower heights due to operational reasons associated with ground control problems. These geotechnical factors, together with logistical issues associated with size, weight and stability concerns with the very large, high face equipment, are considered to be major limitations to this method finding application beyond 6m height for the foreseeable future

Some pertinent comments in relation to these international faces and recent experience, are as follows

- The Lazy Mme in the Czech Republic, with 6m equipment designed to cut at 5 5m, is currently operating at a maximum cutting height of between 4m and 4 5m due to difficult ground conditions (roof and face)
- The Sihe Mine m China is currently experiencing ongoing difficulty holding the coal roof above the supports and ahead of the longwall face (between the tip of the roof supports and the coal face being cut by the shearer) As a result, although cutting to 5 5m with no excess height capacity in the supports (to allow extension to provide improved roof control), the face continues to experience ground control problems It is understood that Sihe has recently called tenders for 6 2m high supports - not ne^ ^ssanly to cut higher, but to provide the necessary Duffer of support capacity above cutting height

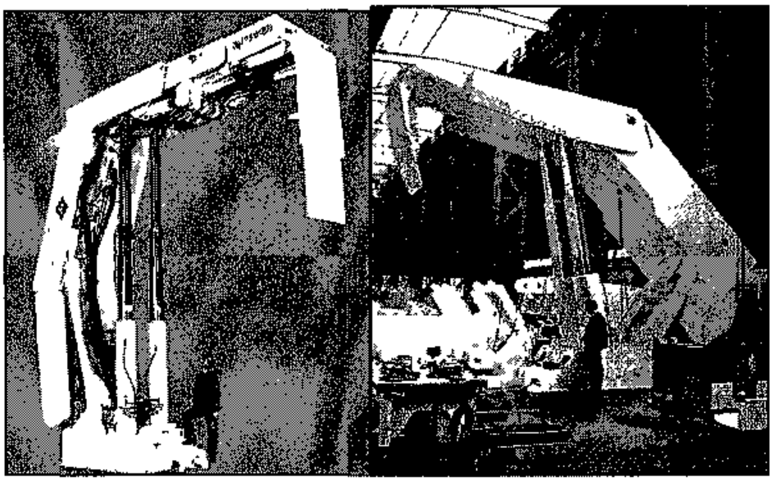
The Matla face in South Africa is operating at a relatively shallow depth (typically less than 100m), with quite massive overburden strata and relatively strong coal Nevertheless, it is understood that Matla is currently experiencing ground control problems in difficult ground, and as a result has reduced the cutting height to approximately 4m under these conditions

Table 2 Australian Thick Seam Single Pass Longwall Operations (2004)
(source Australia 's Longwalls - March 2004 & Sept, 2004, plus pers comm)

Mme	**Face height (maximum) (m)**	**Maximum LW support height (m)**	**Face length (maximum) (m)**	**Shearer drum diameters (m)**	**LW face production (Mtpa)** (12 months to June 2004)	**Total mine production (Mtpa)** (12 months to June 2004)
Moranbah North	45	**48**	300	25	1863	2 128
Newlands	**50**	50	270	25	5 540	5 780
North Goonyella	42	**53**	300	24	1756	1903
West Wallsend	**48**	**53**	260	25	3 042	3 266
Manda long	**50**	52	125	26	Not yet in production	
Broadmeadow	**50**	**52**	7	7	Not yet in production	

Table 3 International (beyond Australia) Thick Seam Single Pass Longwall Operations (2004)(jo«rce *DBT)*

Mine	**Face height (maximum) (m)**	**Maximum LW support height (m)**	**Face length (maximum) (m)**	**Shearer drum diameters (m)**	**LW face production (Mtpa)** (12 months to June 2004)	**Total mine production (Mtpa)** (12 months to June 2004)
Lazy Mine, Czech Republic	55	**60**	100	2 75	9	7
Sihe Mme, China	55	55	225	7	7	7
Shendong, China	**50**	55	240	9	9	+8Mtpa (see previous figures for older face)
Damng Mme (AACI), China	50	55	7	7	Equipment ordered in 2004	
Zhouchuang Mine, China		**60**	7	7	Face equipment (shearer) tender out, late 2004	
Shangwan Mine, China	50	55	240	7	7	7
Mada Mine, South Africa	**55**	**60**	140	7	7	7



(a) DBT 6m support for Lazy Mine, Slovakia

(b) DBT 6m support for Matla Mine, South Africa *(photographs courtesy ofDBT -personal communication}*

Figure 1. DBT 6m supports

The point of presenting the above summary of statistics and experience in the SPL system is to illustrate that SPL is certainly a technically feasible system in terms of equipment, within the 5m to 6m height range. However, in terms of operating experience at these heights, there are only two faces operating at heights between 4.5m and 5.0m, albeit only a small number of faces still. Once face height reduces below 4.5m then the number of successful faces increases significantly as the risks reduce.

Figure 1 shows longwall face supports recently delivered by DBT to the Lazy Mine in Slovakia and the Matla Mine in South Africa. Supports such as these typically have a collapsed height of 2.55m, width 1.75m, weigh up to 39 tonne, and have a support capacity in excess of 1,000 tonne.

4 HYDRAULIC MINING

Historically, most hydraulic mines around the world were simply niche applications of a technology with far greater potential than initially realised. These mines were developed with their primary purpose as an alternative to mechanised mining techniques. The seams in which these hydraulic mining techniques were applied, were predominantly steeply dipping and hence, mechanised methods had little to no application. In Australia only a very small proportion of the total thick installed faces, worldwide, at present (Lazy and Matla), and both are experiencing difficulties and have been forced to reduce mining height significantly. At lower heights, both the equipment performance and geotechnical risks reduce, and there is certainly more experience worldwide with seam tonnage falls into this steeply dipping category *(greater than 15 degrees).* Therefore, the application of hydraulic mining in this country would have to be in gently dipping *(less than 15 degrees)* seams. However, in thick coal seams, it is possible to operate at apparent dips in excess of the actual seam dip, hence hydraulic mining can find application.

Previous hydraulic mine operations have existed in places such as Germany, Canada and Japan. More recently the mines operated by Solid Energy on the South Island of New Zealand have utilised this method with considerable success. The Strongman No. 2 Mine (recently closed) operated by Solid Energy, was producing in excess of 400,000 tonnes/yr using a single hydraulic monitor (plus conventional continuous miner development units). The technique is currently being implemented in the new Spring Creek Mine in New Zealand. Features of the method are relatively low capital cost and the flexibility of multiple operating faces - provided conditions are suitable.

Figure 2 illustrates the concepts of underground hydraulic coal mining. Hydraulic mining has several advantages over conventional mechanised mining methods. However, it is important to note that not all coal seams are compatible with hydraulic mining. As mentioned above, a number of specialised geological parameters must be satisfied before hydraulic mining can be undertaken. The advantages of hydraulic mining are:

- Mining layout is similar to that for conventional mechanised bord and pillar mining; however, the level of mechanical complexity is significantly reduced.

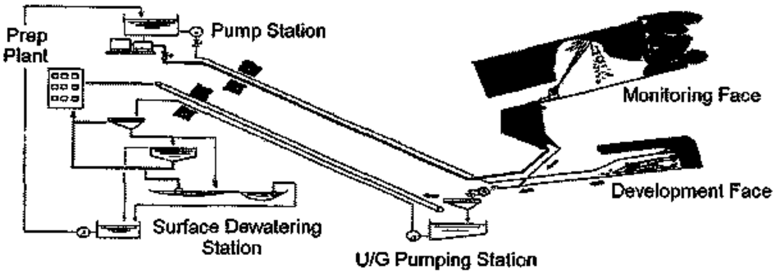


Figure 2 - Concept of Hydraulic Mining

- Due to a reduction in the production of coal dust, the elimination of frictional ignition sources, the removal of personnel from the face area and the ability to automate equipment operation, hydraulic mining can be relatively safer than more traditional underground coal mining methods.
- Extraction of thin (0.3m - 1.5m), thick (> 4.5m) and steeply dipping seams has, in the past, challenged traditional mechanised techniques. However, hydraulic mining has had great success in such geologies.
- Typically the tonnages obtained from hydraulic mining operations are less than those obtained from mechanised methods. However, due to reduced manning requirements and lower capital costs, hydraulic mining is still highly productive.
- Hydraulic mining offers significantly lower capital and operating cost structures over conventional mines, particularly if the mining faces are located above the drainage level.

« Hydraulic mining is operationally flexible and can be used to extract areas of working mines where mechanised methods would otherwise encounter operational difficulties or would be economically unfeasible.

- Provided mine layout is designed appropriately, hydraulic mining can cope with large scale structural disturbances; and as a result the profitability of a hydraulic mining operation is less affected by these constraints.

Hydraulic mining also has some disadvantages - they are:

- The entire mine must be planned around the gravity driven hydraulic transportation system; roadways must have an average inclination of at least 4.0°, even if this means coal is left in the floor.
- High influx of water can cause problems with acid mine drainage; this acidity increases with high sulphur coals.
- Hydraulic mining can require the consumption of larger volumes of water and more electricity than conventional mechanised techniques; this is especially true for operations where the drainage level is underground.
- Coal is broken along its entire transportation route resulting in higher levels of fines in the run-of-mine product. This increases the capital and operating cost of dewatering facilities.
- The risk of spontaneous combustion is greater than for conventional techniques due to irregular goafing and difficulties in sealing off areas.
- Water reduces the strength of geological materials and therefore there may be an increased propensity to roof falls.
- During coal extraction the operator is unable to see the coal face and as a result is unable to ascertain exactly what is happening. As a result, a sudden collapse of roof strata may bury the monitor/face equipment.

In summary, hydraulic mining has limited potential, but in the right conditions, can be a highly productive, low capacity thick seam mining method.

5 THE LTCC METHOD

During the ongoing research and status review work into thick seam mining methods, the various Australian research teams became aware of the significant developments and impressive performance improvements being achieved in China with the development and application of the LTCC method (Xu, 1999). The method is essentially an extension of the original soutirage concept, but with significant equipment and face operational changes related to the use of the second rear AFC behind the face for handling the caved coal (see Figures 3, 4 and 5).

In terms of equipment innovation, the more recent Chinese developments have relocated the top coal draw points to the rear of the longwall supports, rather than bringing coal through the roof canopy of the shield onto a conveyor within the shield structure. These previous methods were quite clumsy and mechanically complicated, quite apart from the excessive dust-make within the face area and the 'cluttering up' of the already limited space within a line of shield supports. The Chinese equipment has a pivoting supplementary goaf or tail canopy behind the support. Beneath this is a retractable second AFC. With the rear AFC extended and the rear canopy lowered/retracted, caved top coal can be loaded onto the rear AFC, whilst production continues conventionally in front of the supports. In the retracted rear AFC position with the rear canopy raised, the supports and face operation can function conventionally.

The Chinese industry had reported averages of 15,000 to 20,000 tpd from an LTCC face; up to 75% recovery of 8m+ thick seams using a 3m operating height longwall; and +5 MTPA face production. There are now well over 70 LTCC faces in China. A new semi-automated 300m long LTCC face was installed at the Xinglongzhuang Colliery of the Yankuang Group, in Shandong Province, in August, 2001, with production capacities of at least 7MTPA.

The major perceived benefits of the LTCC method for Australia include:

- Operating Cost Reductions: The LTCC method enables potentially double (or greater) the longwall recoverable tonnes, per metre of gateroad development, thereby reducing the development cost/tonne significantly, and reducing the potential for development rate shortfalls leading to longwall production disruption.
- Resource Recovery and Mine Financial performance: The LTCC method offers a viable means of extracting up to 75% to 80% of seams in the 5m - 9m thickness range. Single pass longwall is considered to be limited to an upper height of 6m, and is currently only operating at or below 5m.
- Mine Safety: Lower face heights (relative to high reach single pass longwall) result in improved face control, smaller and less expensive equipment and improved spontaneous combustion control in thick seams, through removal of the majority of top coal from the goaf.

A joint ACARP research project between UNSW and CSIRO was undertaken to further investigate the LTCC method for Australian application, and was reported in 2003 (Kelly et al., 2003). In parallel with the ACARP study, UNSW and CSIRO jointly developed a relationship with the Yankuang Group in China, one of the leading operators of the LTCC method. Various study visits by UNSW, CSIRO, CMTE and industry representatives from Australia visited China to inspect the LTCC operations of Yankuang and other companies over the past five years. All groups have returned with very favourable impressions and views about prospects for the method in Australia.

6 GEOTECHNICAL ISSUES FOR LTCC

The success of an LTCC operation - from all three perspectives of safety, resource recovery and productivity - depends to a large extent on having an appropriate geotechnical environment, and then successful geotechnical management within that environment. This has been recognized by Chinese operators who have developed a number of reliable empirical classification and design schemes.

The geotechnical factors considered to be of most importance for safe and effective implementation of LTCC in Australia are considered to be the following:

- coal seam cavability/fragmentation
- effect of massive strata units in immediate/near seam roof
- effect of high horizontal stress ratios

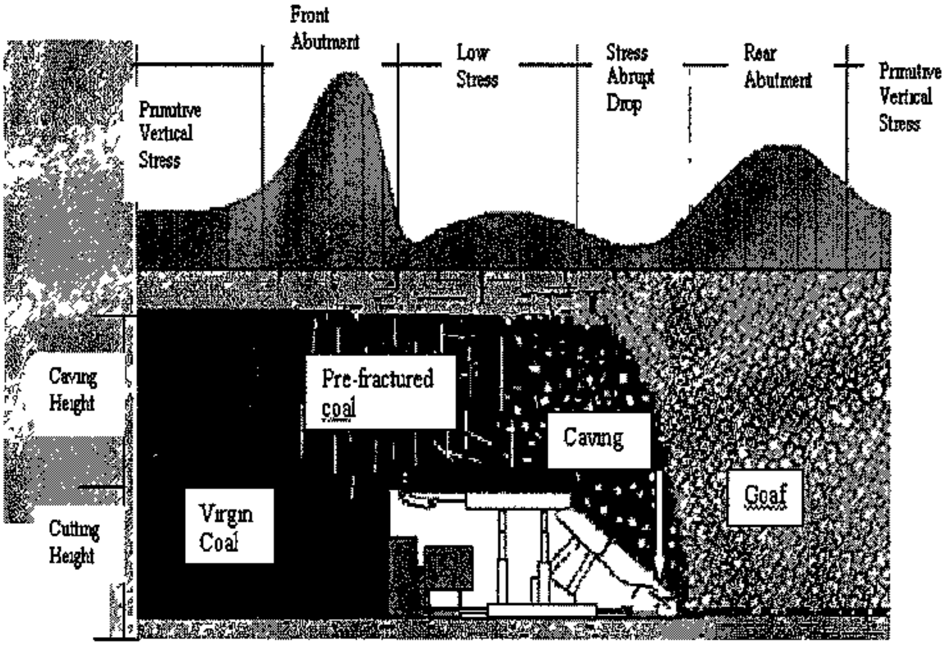


Figure 3 Conceptual Model of LTCC System *(after Xu, 1999)*

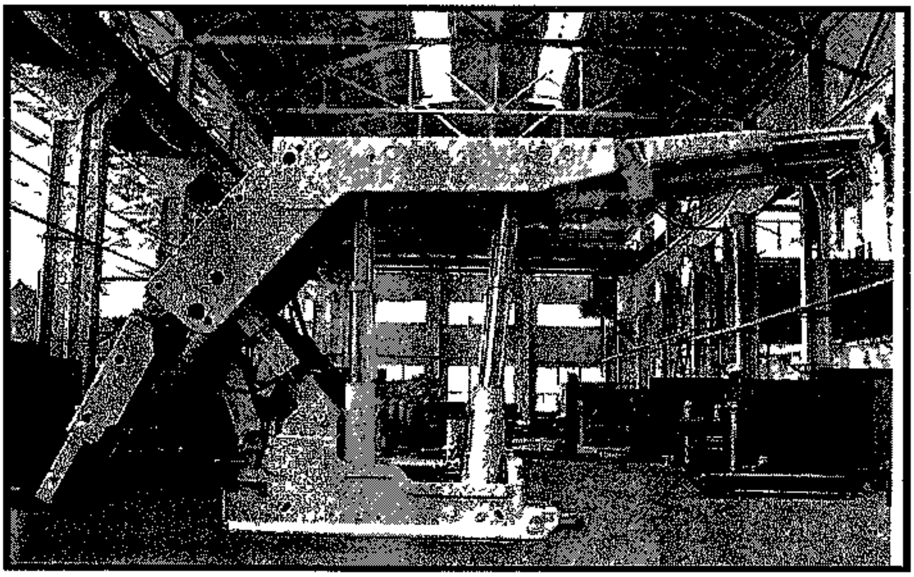


Figure 4 Typical LTCC Face Support (note articulated rear canopy)

Figure 5. View along rear conveyor

6.1 Coal seam cavability

The consistent cavability of the top coal in an LTCC operation is crucial to its success, particularly with respect to adequate resource recovery. If the coal caves, but in too large a pieces it can cause blockages and handling problems both feeding onto, and traveling along the rear conveyor. Of even greater problem is if the coal hangs up, even only for a short time, such that it caves but beyond the reach of the rear AFC. On the other hand, if the coal is too weak and friable, there is the potential for the coal roof to commence breaking up too far in advance of the rear support canopy, leading to potential face and roof problems. The main geotechnical components affecting coal cavability are uniaxial compressive strength (UCS); cleat, bedding and other discontinuities; and vertical stress on the coal.

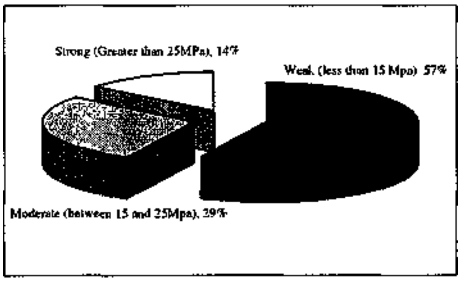


Figure 6. Australian thick coal seam strength distribution *(after Kelly et ai, 2003)*

In the case of UCS, Chinese experience is understood to be that a range of 15 MPa to 25 MPa is well suited to good caving conditions. Above 30 MPa, caving can become problematic, subject to the other parameters of discontinuities and stress. Figure 6 presents a chart showing the distribution of coal strength, in UCS terms, for thick coal seams considered suitable for LTCC methods on all other grounds. This indicates that at least 29% of seams fit into the middle category (15-25 MPa), with only 14% greater than 25 MPa. Some potential sites within this strong coal category (with UCS values in the range 30 - 40 MPa) are currently subject to further laboratory and in situ investigation, in order to assess the other factors and to what extent they might compensate for the higher strength range. The 57% of coal seams in the sub-15MPa range (predominantly in Queensland) will undoubtedly cave well, but will require more detailed, site-specific studies in relation to immediate roof integrity above and in front of the supports. This may also require adjustment of the initial coal cutting height to secure a stable immediate roof.

The question of depth is also an important issue for Australia. As the figures in Table 1 indicated, 51% of the measured reserves are below 150m in depth. The effect of this is that the amount of vertical stress due to overburden cover, acting on the top coal may be insufficient to fracture the coal sufficiently, particularly if it coincides with a stronger than average coal seam. Once again, it is the combination of all three sets of parameters (and possibly others) which is likely to determine the final cavability assessment This whole question of cavability is the subject of ongoing research in Australia, both from the point of view of coal cavability classification systems, and also in terms of appropriate stress analysis modeling techniques

6.2 Massive roof strata units

The issue to be considered here is the one which a number of Australian mines experience, in terms of periodic weighting, or delayed, cyclical caving of massive roof horizons The effect of these can be no more than nuisance value, right through to damage to face support systems and face/roof instability ahead of the supports

It is the opinion of a number of geotechnical specialists who have visited Chinese LTCC faces, that the "typical" Chinese roof geology (above the coal seam) is more benign than Australia, with respect to these massive units, i e the Chinese stone roof is typically weaker and softer and more amenable to caving The effect of such differences is still the subject of investigation in the form of parametric numerical stress modeling It is speculated that the massive units may produce both benefits and problems on an LTCC face Benefits from the perspective of additional loading on the top coal above the supports as the massive units cantilever back into the goaf, and problems if the delayed caving also inhibits the coal from caving immediately

6.3 High horizontal stress

On this issue also, there remains a need for further investigation The available data on pre-mining stress magnitudes and directions in Chinese mines has not, as yet, allowed quantitative comparisons However, visual evidence from underground inspections would indicate that the horizontal stress regime is less hostile in Chinese mines than many Australian mines, where ratios of between 2 1 and 3 1 are not uncommon (horizontal to vertical stress)

The consequences of such stress fields will obviously depend on many factors including face orientation, discontinuities, massive units etc The concern is that high stresses could inhibit caving by locking the top coal together until after the face and rear AFC has passed Again, this is an area where further work is required

7 LTCC FACE AND OPERATIONAL ISSUES

There are a number of operational issues that have already been alluded to above, such as face orientation, selection of mining horizon, etc. In addition to these, the operational areas considered important for successful Australian LTCC implementation relate primarily to the gate end area (face end support, equipment configurations and coal clearance), face ventilation (gas/dust management), caving management (support operation and dilution control), cutting sequences, and overall coal clearance systems (AFC capacities and compatibility with cutting and caving sequences, BSL, panel belts and outbye coal clearance systems) There is ongoing research being conducted into the overall cutting, caving and clearance options in order to gain maximum productivity from the LTCC system One interesting option under consideration is the use of two panel belts - one in each of the maingate and tailgate - to separate the coal flow from the two AFCs This has obvious benefits and applications, at least in non-gassy mines, and particularly where the coal from the lower horizon may be of a different quality to that within the top caved coal horizon

8 CONCLUSIONS

In summary, Australia certainly has extensive underground thick seam reserves that require the development and application of new or modified mining methods

- Multi-slice longwall methods are not considered to have application, due to safety concerns and perceived productivity problems
- Single pass longwall methods will find application in the 4 5m to 6m height range, although problems associated with ground control and face stability, together with equipment handling and operational issues with such large equipment, are yet to be effectively overcome
- There are large reserves of thick seam coal in Australia in the 6m-9m thickness range, that appear well suited to the rapidly developing Chinese LTCC method It is clear that there is considerable experience to be gained from the impressive Chinese developments with this method and the results that have been obtained to date

In terms of implementation within Australia, there appear to be no insurmountable impediments to the introduction of the LTCC method, although there are a number of operational, geotechnical, safety and equipment issues that do require further investigation, design and development, as well as some site specific design issues

Acknowledgements

The author wishes to acknowledge the financial support of various funding bodies for the work conducted to date (including ACARP, UNSW, ARC and Yankuang Group), as well as the co-operation and valuable input from their collaborative research partners (CMTE and CSIRO) and various industry representatives in both Australia and China

REFERENCES

Hebblewhite B, Simonis A & Cai Y (2002) Technology and feasibility of potential underground thick seam mining methods School of Mining Engineering, UNSW/CMTE ACARP Project C8009 Final Report UMRC 2/02 ISBN 0 7334 1945 3

Kelly M, Wnght B, Cai Y, Hebblewhite B, Onder U & Xu B (2003) Application of longwall top coal caving to Australian operations CSIRO Exploration and Mining/School of Mining Engineering, UNSW ACARP Project CI 1040 Final Report 1137F

Hamilton N (1999) Single pass thick seam longwall experience at West Wallsend Colliery 2nd Intl Underground Coal Conf, UNSW, Sydney, Australia, 15-18 June, 1999,pp55-61 ISBN 1 876315 17 2

Hebblewhite B (1999) Overview of Australian thick seam mining prospects 2nd Intl Underground Coal Conf, UNSW, Sydney, Australia, 15-18 June, 1999, pp29-36 ISBN 1876315 17 2

Paiarski J (1999) Multi-slice longwalling with backfill 2nd Intl Underground Coal Conf, UNSW, Sydney, Australia, 15-18 June, 1999, pp37-46 ISBN 1 876315 17 2

Bassier R & Mez W (1999) Application of paste fill in active longwalls and for stowage 2nd Intl Underground Coal Conf, UNSW, Sydney, Australia, 15-18 June, 1999, pp47-54 ISBN 1 876315 17 2

Xu B (2001) The longwall top coal caving method for maximizing recovery at Dongtan Mine 3rd Intl Underground Coal Conf, UNSW, Sydney, Australia, 12 - 15 June, 2001, unpag ISBN 0 7334 1812 0