



# Meeting the Geotechnical Challenges at two Mongolian Mining Corporation Coal Mines

Presentation to Bowen Basin Open Cut Geotechnical Society  
(BBOCGS)

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By

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# Ukhaa Khudag Mine (UHG)

UHG pit overall panorama view



Photo view around the pit



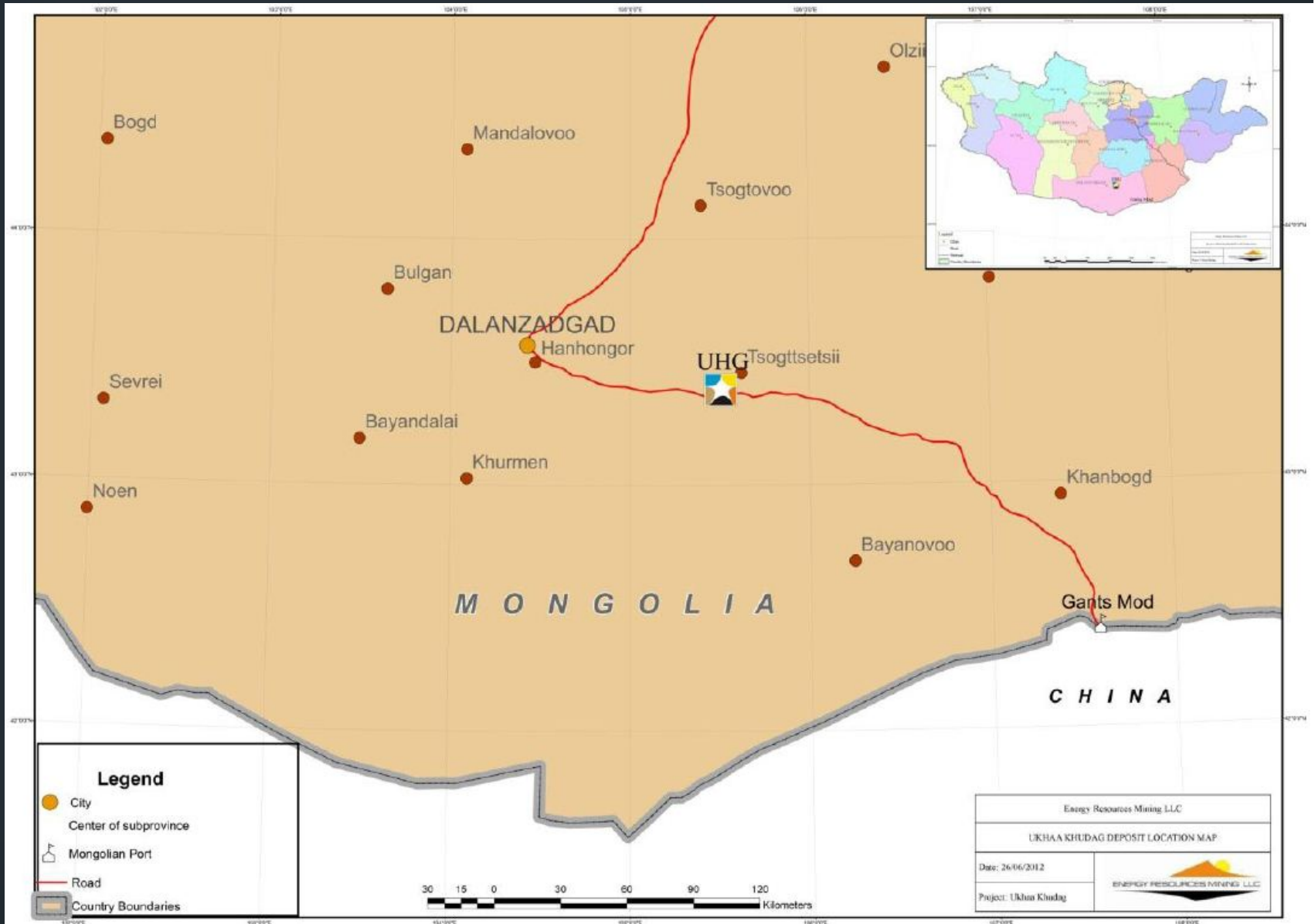
# Background and History

- The license number (11952A) held by ER LLC (MMC)
- First exploration work by a Mongolian/Russian team from 1985-1987
- UHG detailed exploration work was done by Norwest LLC in 2008
- UHG mining started in August, 2008
- Next detailed exploration work was done by ER LLC between 2009 and 2011
- 2D seismic work was done by Polaris International (from Canada) in 2010 and 2011 – processing and interpretation by Velseis
- JORC standard resource report compiled 2012 by MMC and ER Geology

# Background and History

- Ukhaa Khudag deposit forms part of the northern extension of greater Tavan Tolgoi coalfield and covers approximately 29.6 km<sup>2</sup>
- The coalfield is located in south-central Mongolia within the Ulaan Nuur Valley of the Gobi Desert
- The coalfield is situated within the Omnogobi aimag about 90km east of Dalanzadgad, the provincial capital, and some 550 km south of Ulaanbaatar, the national capital. The coalfield is 240 km from the border of the People's Republic of China to the south
- UHG coal formation comprises 18 seam groups

# Locality



# Infrastructure

- Tavan Tolgoi airport (7 km from the UHG mine site)
- A fully sealed 240 km two lane highway from UHG to Gashuun Sukhait, the Mongolian coal port 30 km from the Chinese border
- Tsogttsetsii, a small aimag located 5 km from the mine.
- Workers town Tsetsii khoroolol (2011) and Gallery camp (2009)
- Wash plant (CHPP built in June, 2011)
- Power plant ( 2010)
- Workshop
- Laboratory
- Tailings dam
- Central office building

# Tavan Tolgoi Airport



Airport is located 7 km from the UHG mine site

# Town and Small Aimag (soum)



# CHPP, Power Plant and Workers Camp



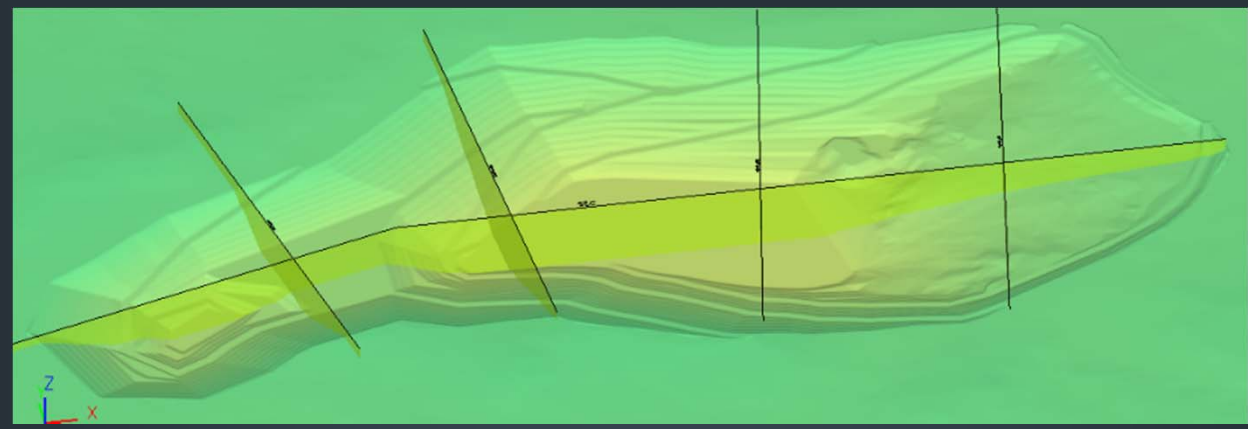
# Mining Method

- Truck and shovel
- Multiple seams generally dipping  $3^{\circ}$  to  $17^{\circ}$
- Terrace mining with steep dipping flanks
- Ex-pit dumping

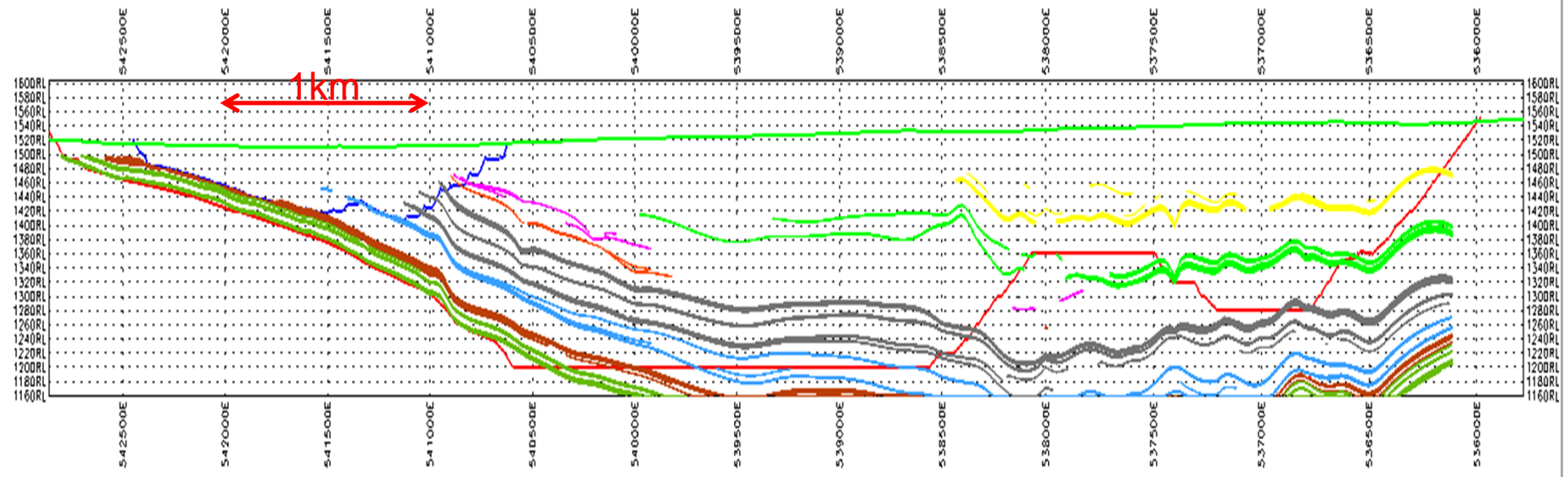
# Equipment Inventory

Type	No	Type	No
<b>Excavators</b>		<b>Dozers</b>	
Liebherr 996	4	Cat D10T	10
Hitachi 3600	3	Cat 854WD	1
Liebherr 9250	2	Cat D9T	2
Hitachi 1200	2	<b>Drills</b>	
<b>Loaders</b>		Sandvik D45KS	5
Cat 992K	3	Sandvik DP-1500	1
Cat 988H	2	<b>Water trucks</b>	
<b>Graders</b>		Cat 773E	1
Cat 16M	5	Cat 773D	4
Cat 14H	1	<b>Haul trucks</b>	
Cat 14M	1	Cat 793D	38
		Cat 785C	24
		Cat 777D	26

# Coal Seams

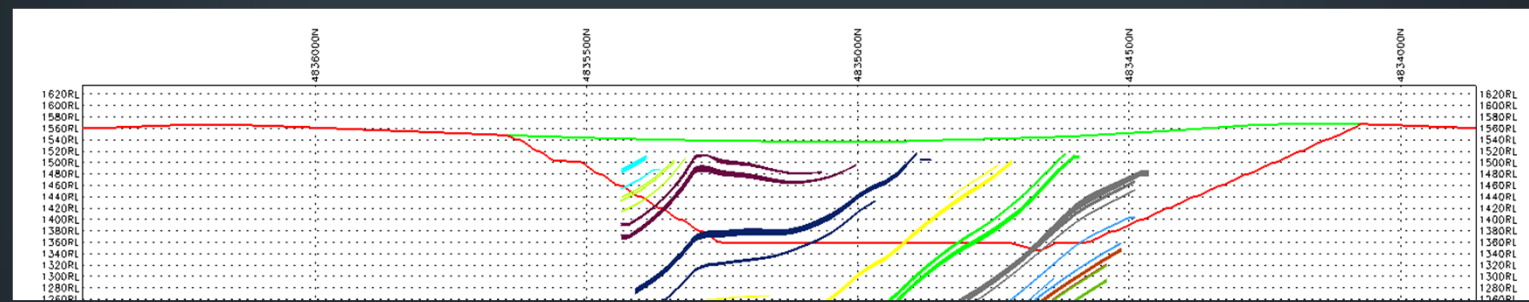
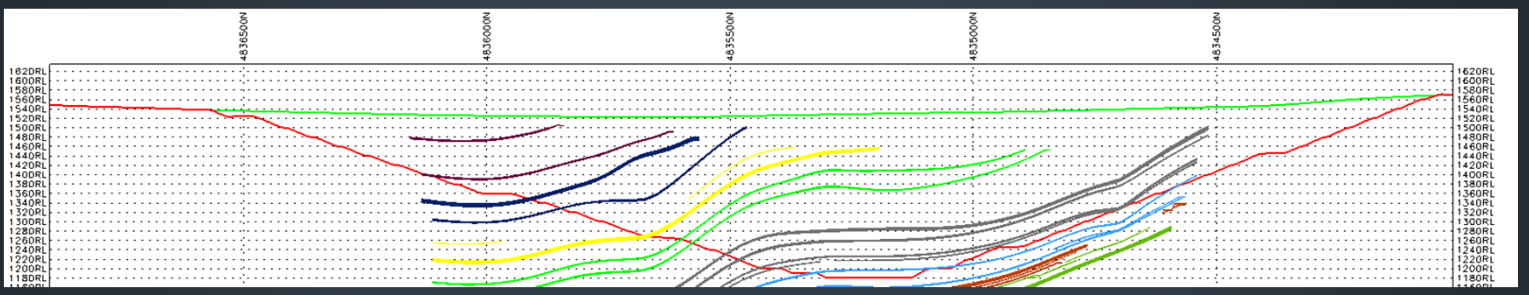
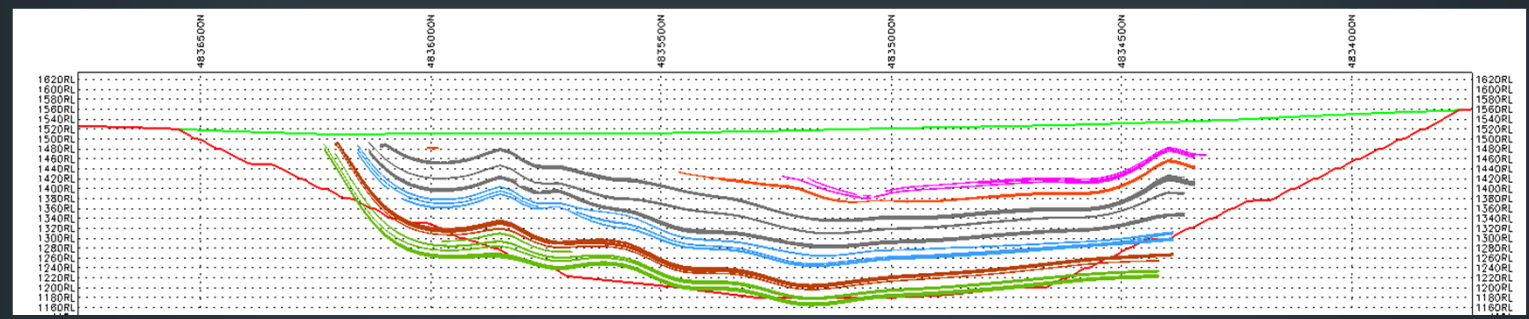


Cross section E-W view



# Coal Seams

## N-S Cross Section Views in E-W Direction Order



# Geological Structure

- Very complex with multiple major disturbance phases.
- Main northern and southern fault zones (boundary faults) plus numerous other faulted zones (fault corridors) which still contain coal seams but are difficult to model and predict their structure.
- Complex structural history - suspected history along the northern boundary fault illustrates this – next slide.

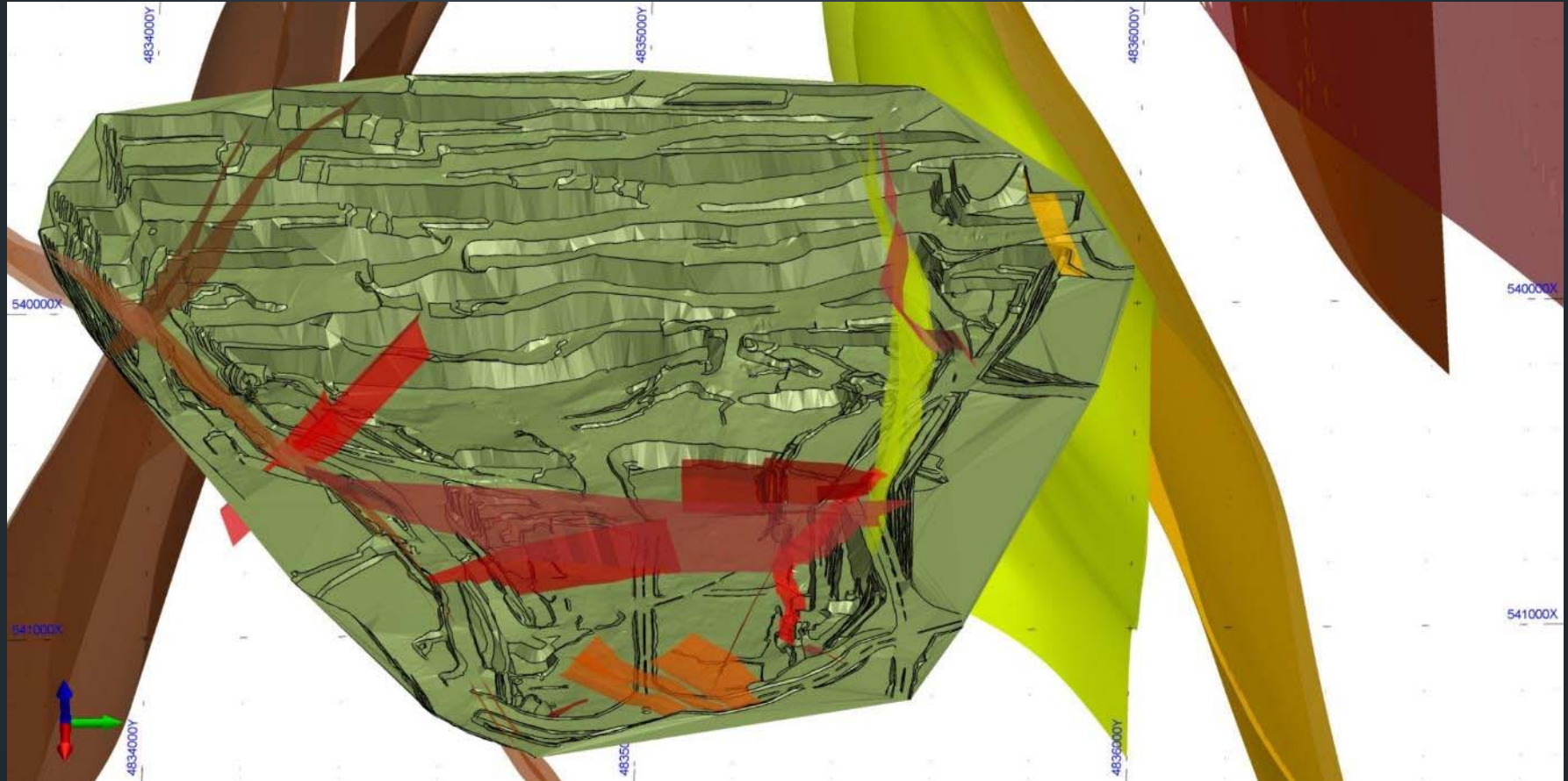
# Geological Structure

## Possible Structural Sequence (Godfrey 2012)

- North–south compressional forces forming east–west trending anticlines and synclines.
- More severe continued north–south movement creating differentially steep folding with eventual vertical axes.
- East–west compressional pressures move the rock differentially horizontally with some rotational component resulting in tearing off of some large fragments.
- Further north–south movement during this time with overall rotational movement resulting in wavy folding of bedding. Resultant torsional effects may have resulted in occurrence of normal faulting and graben formation.
- The final movement would have been the uplifting of the lightly disturbed lutite block to the north of the northern fault zone.

# Geological Structure

## Regional and Local Faults (3D View with UHG Current Pit Shell)



# Main Slope Failure Modes

- Structure more than rock strength defines slope behaviour.
- The main failures have been along bedding plane shears mostly associated with coal seams – 0CU seam appears to be the most problematic and is classified as a “serial offender”.
- Large planar failures (up to 700 m x 300 m ) on end walls along relatively shallow dipping bedding plane shears even with low overall slope angles. These failures are often, but not always, associated with ramps.
- Medium planar failures (up to 100 m x 40 m) along steeply dipping boundary faults.
- Other failures have been along unfavourably dipping faults and in weathered overburden when mined too steeply.

# Rock Mass Strength

## Challenges

- Limited laboratory test data for UHG
- Challenges with lab testing
  - No local rock strength laboratory
  - Currently use national university in Seoul
  - Plenty of “red tape” in exporting samples
  - Very difficult to get samples to the lab within recommended 30 days
  - Generally weak and disturbed borehole core
  - Samples are well wrapped and also splinted to minimise damage during transit

# Rock Mass Strength

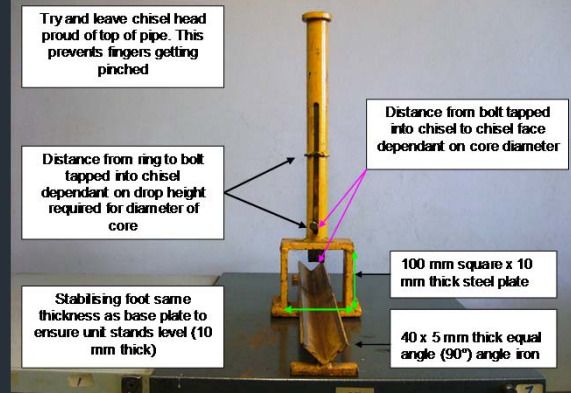
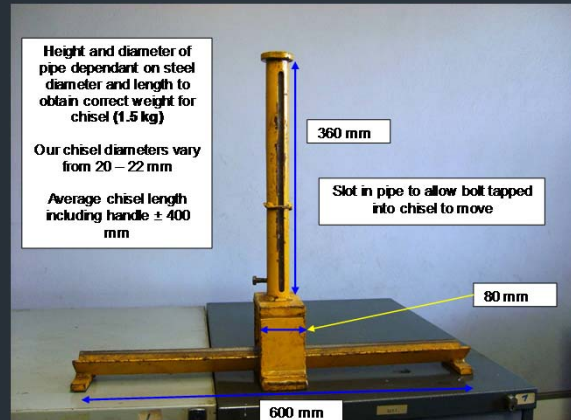
## Responses

- Point load testing to estimate UCS
- Impact splitting appears to be a good rough indicator of strength and is easy to use and apply
- Field estimates based on ISRM strength tables
- Next step – additional geotechnical boreholes to cover next two years mining area. Extensive laboratory sampling to build up database and calibrate point load and impact splitting results
- Obtain Schmidt hammer for testing host rock either side of structure

# Impact Splitting

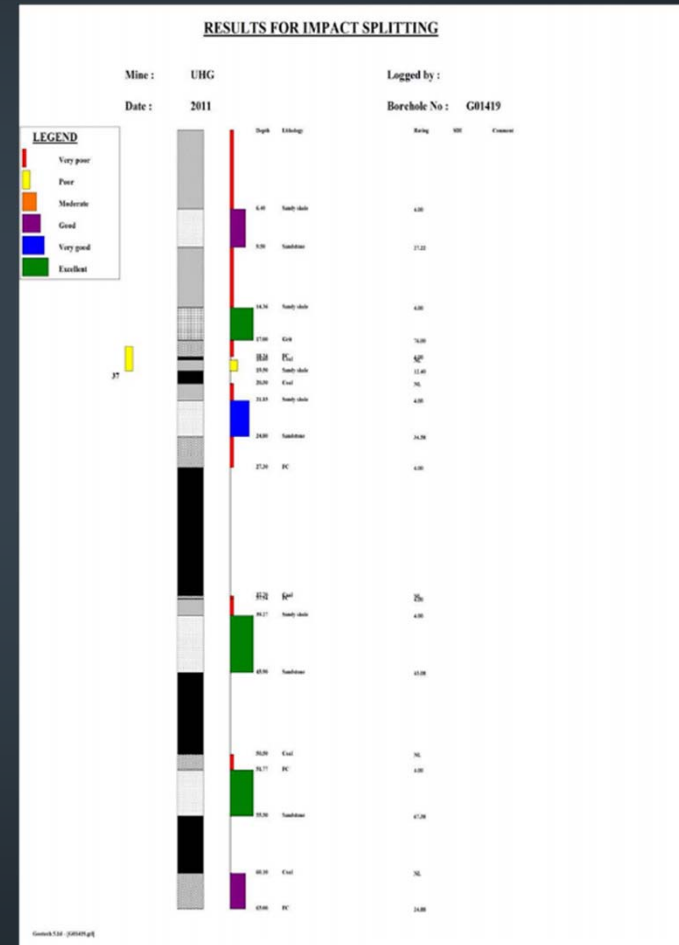
- IS consists of dropping a chisel of prescribed weight from a fixed height and a fixed distance apart along the core. Chisel is oriented to strike roughly parallel to bedding
- Originally used as a test suitable for rating laminated coal mine roof strata in underground S African collieries
- Advantage is that even very weak material can be rated and coal can have IS done before coal quality samples are analysed
- IS software being updated to better suit UHG conditions

# Impact Splitter and Results



The drop height for various core diameters is standardised to be equivalent to dropping the chisel from a height of 100 mm onto TNW core. For any other core diameter the following simple equation may be used to determine the chisel drop height ( $h_d$ )

$$h_d = \frac{A}{28.27} \text{ mm} \quad \text{Where: } A = \text{cross sectional area of core (mm}^2\text{)}$$



# UHG Geotechnical Domains

## Main Units Defined for Limit Equilibrium Analyses (Galena)

- Weathered overburden
- Moderately weathered overburden



# UHG Geotechnical Domains

Fresh overburden (mudstone and siltstone)



Sheared coal



Fresh coal



Major fault zone



# UHG Geotechnical Domains

Strong sandstone



Tsogttsetsii Formation



Bedding plane shear



Sheared zone



# Discontinuities

## Challenges

- Major problem with bedding plane shears mostly, but not always, associated with coal seams (slope scale)
- Secondary problems with major faults which are often thrust faults (slope and batter scale)
- Other structurally driven problems
  - Rockfalls due to blocky nature of UHG rock
  - Overhangs due to self mining of highly fractured underlying units (usually mudstone)
- Identification of discontinuities can be difficult in places on the highwall due to buffer blast material lying over bottom half of batters
- Endwalls have steeply dipping strata – flanks can dip out of the pit wall by between 10° and 35°
- Highwall dips into the pitwall of 3° but up to 17° in places
- At present dumping ex-pit but possible in-pit dumping in future will need to keep footwall shears in mind.

# Discontinuities



# Discontinuities

## Structurally Driven Slope Failure Examples, #1 N Boxcut Ramp

Top of boxcut ramp failure



Close-up of bedding shear (dip  $\pm 15^\circ$   
flattening to  $\pm 8^\circ$  towards failure toe)



# Discontinuities

Near bottom corner of failure

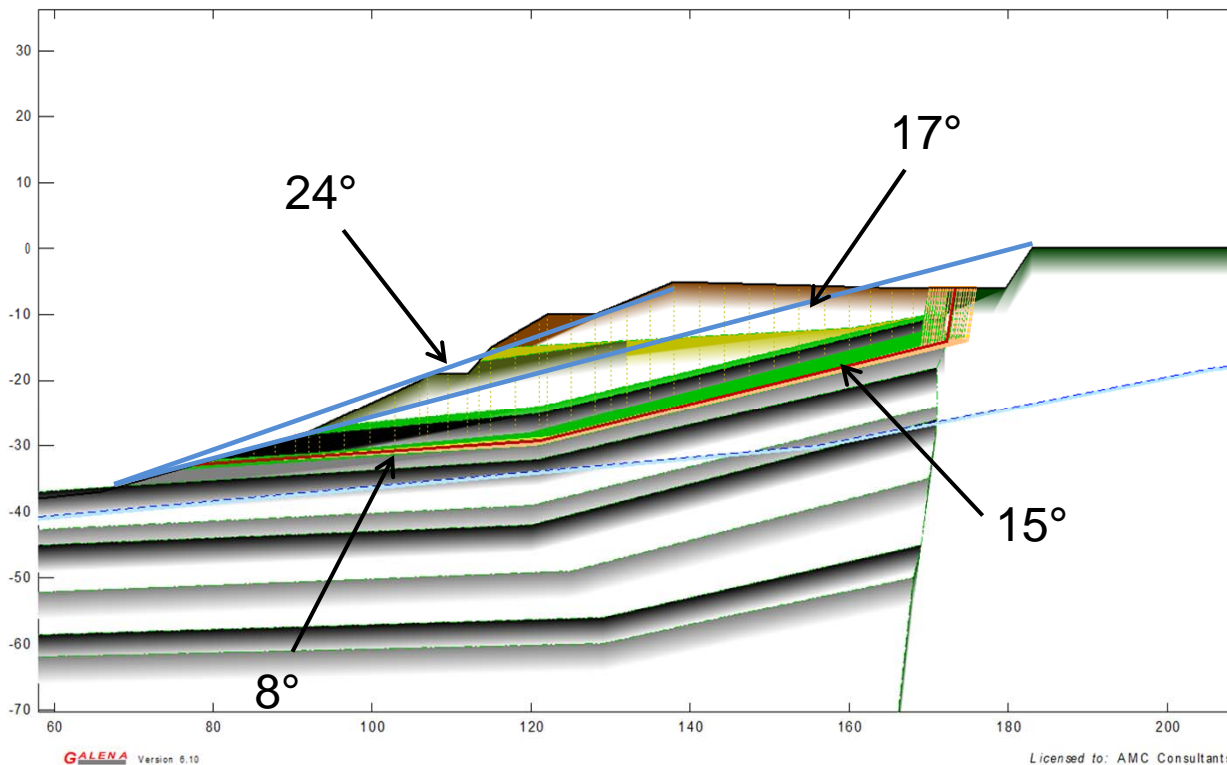


Sheared and faulted zone along part of the eastern flank of failure



# Discontinuities

## N Boxcut Ramp Galena Cross Section



### Material Keys

Weathered overburden (WOB)	(c:28 ø:19 g:22)
Moderately weathered overburden (MWOB)	(c:107 ø:30 g:23)
Fresh overburden - silt/mudstone (FOB)	(c:298 ø:41.5 g:25)
Coal fresh (CF)	(c:29 ø:23.5 g:15.2)
Bedding plane shears (BPS)	(c:1.5 ø:13 g:18)
weathered coal (CW)	(c:17 ø:20 g:17)
Major faults & shear zones (FSZ)	(c:20 ø:18 g:20)

### Analysis 1

Multiple Stability Analysis  
 Method: Spencer-Wright  
 Surface: Non-Circular

### Results

Critical Factor of Safety: 1.03  
 Interslice Force (Final) Angle: 11.6°

Edited: 19 Oct 2012  
 Processed: 29 Aug 2013

# Structurally Driven Slope

## Failure Examples, #2 Southern Endwall

Panoramic view



# Discontinuities

Crack through ramp at base of failure



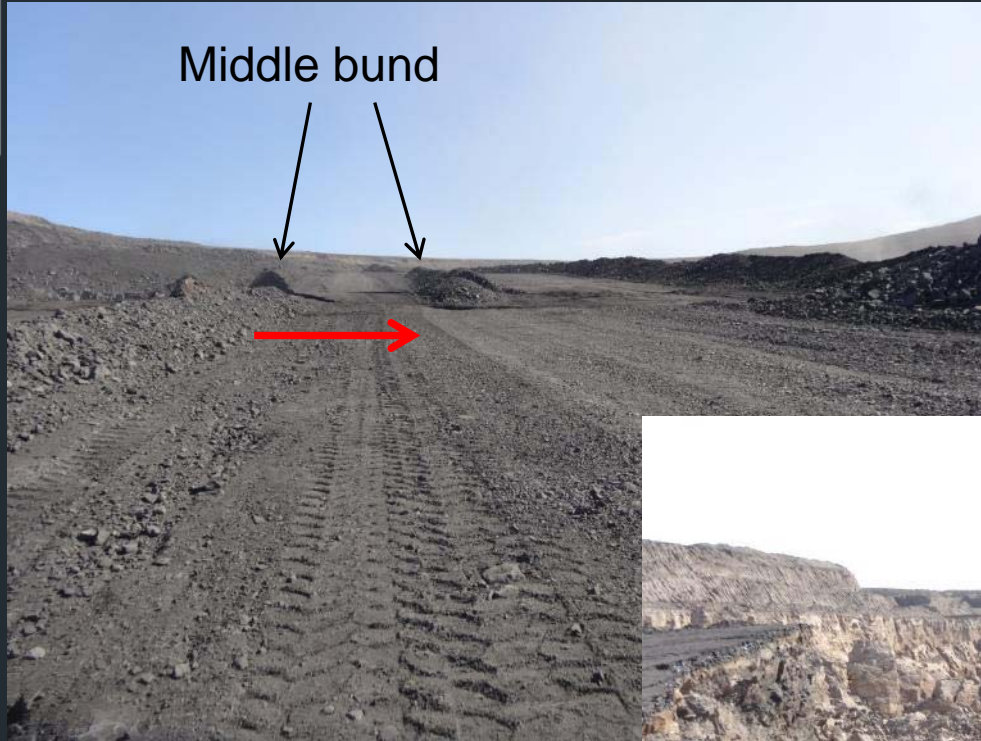
Front face of failure



Compression features along top edge of failure



# Discontinuities



Crest area



# Discontinuities

Crest failure and jointing – remains of  
crack meter



Shear zone on south west side of  
failure – horizontal striations



# Discontinuities

View from western highwall

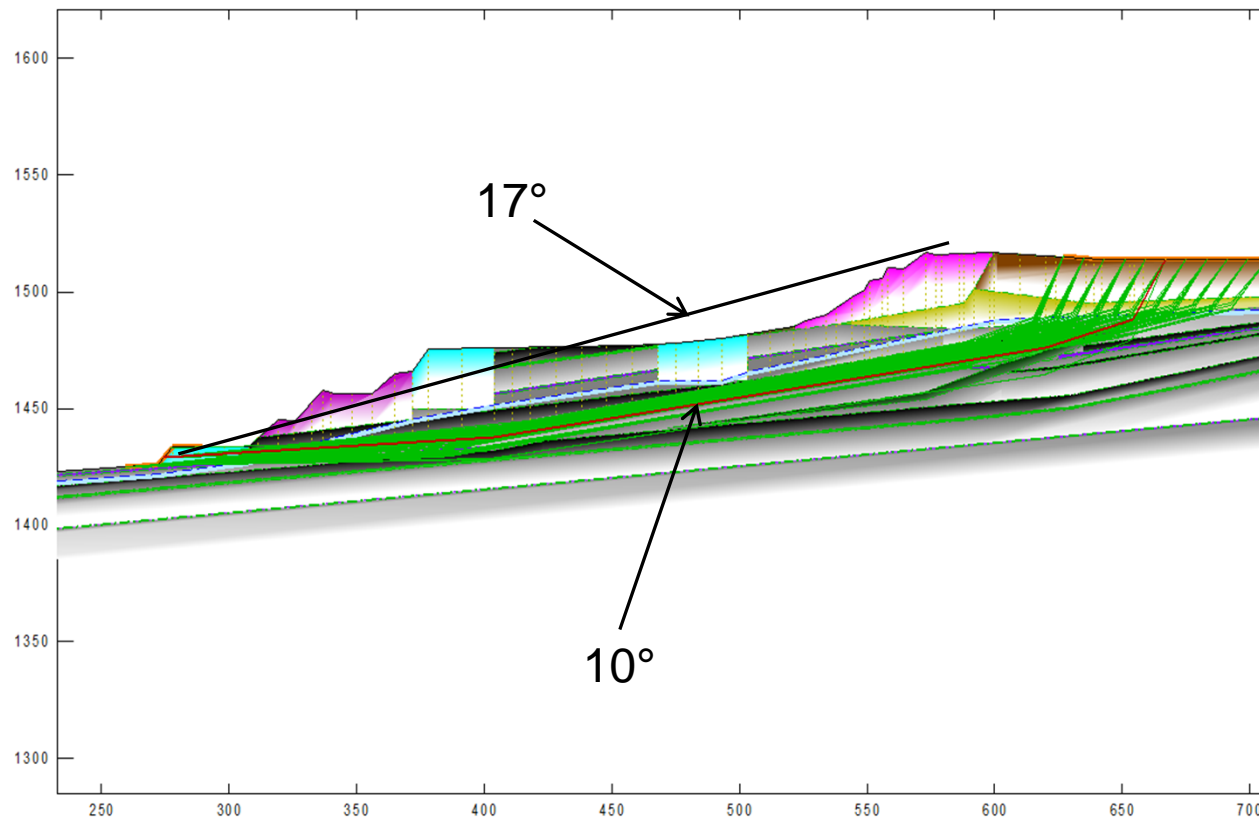


Major axis along shear zone



# Discontinuities

## S Endwall Failure Galena Cross Section



**Material Keys**

Weathered overburden (WOB)	(c:35 ø:19.2 g:22)
Moderately weathered overburden (MWOB)	(c:126 ø:30 g:23)
Fresh overburden - silt/mudstone (FOB)	(c:283 ø:37.5 g:25)
Coal fresh (CF)	(c:34 ø:25.6 g:15.2)
Sheared coal (CS)	(c:17 ø:18.5 g:14)
Bedding plane shears (BPS)	(c:1.5 ø:13 g:18)
Blasted rock (BR)	(c:76 ø:35 g:21)
weathered coal (CW)	(c:17 ø:20 g:17)
Major faults & shear zones (FSZ)	(c:25 ø:18 g:20)
Existing failure in WOB	(c:10 ø:8 g:20)
Existing failure in fresh overburden	(c:22 ø:20.7 g:22.5)

**Analysis** 13  
 Multiple Stability Analysis  
 Method: Spencer-Wright  
 Surface: Non-Circular

**Results**  
 Critical Factor of Safety: 1.38  
 Interslice Force (Final) Angle: 9.1 °

Edited: 29 Aug 2013  
 Processed: 29 Aug 2013

# Structurally Driven Failure Modes

- Planar failure along bedding shears is predominant
- There is a propensity for endwall slope failures to occur beneath ramps – mechanism unclear (blasting should affect all slopes irrespective of whether they have ramps or not – may be vehicle loads/vibration)
- Failure of a slope with  $FOS > 1.2$  and  $OSA < 20^\circ$  suspected due to blasting
  - First cracks behind crest after a blast
  - Cracks widened considerably after boxcut blast and kept opening
  - Geotechs monitored cracks opening and issued warning
  - Exclusion zone around suspect area established with bunds
  - Failure extended outside exclusion zone along unidentified shear zone
- PPV for blast causing failure was difficult to determine (no site seismograph)
- Various authors and varying equations / constants found, using suggested approaches from literature for sedimentary strata

# Boxcut Blast PPV Values

Point of interest	Distance (m)	PPV (mm/sec)			
		Muller (2007)	Naismith (1984)	ODOT (2006)	Average
Edge of blast block to closest point on ramp	22	2073	1289	6783	3382
Shear zone exposure to closest point of blast	39	878	645	2714	1412
Centre of blast block to closest point on ramp	48	643	501	1947	1030
Old shot #481 blast edge to closest point of blast	109	188	186	524	299
Edge of old failure zone to closest point of blast	366	31	43	75	50
Shortest distance from failure crest from closest point of blast	415	25	37	62	41
Furthest distance to crest along projected shear zone from closest point of blast	598	15	24	34	24

Confined boxcut blasts have PPV values 3 to 5 times that of normal (free face) blasts (Naismith)  
 PPV design target determined as 100mm/sec at a distance of 100m

# How Many Blasts Before Failure??

Djordjevic et al (1999) found that the scaled distance (distance / weight per delay <sup>0.5</sup>) could be used as a means of determining how many blasts would be required to induce slope failure. This was for a gold mine in WA but with calibration to local conditions, it could be a very useful tool. Accepting the formula “as is” results in the following for the boxcut blast:

Point of interest	Distance (m)	Scaled distance	Number of blasts to induce failure
Edge of blast block to closest point on ramp	22	0.25	0.01
Shear zone exposure to closest point of blast	39	0.43	0.04
Centre of blast block to closest point on ramp	48	0.53	0.08
Old shot #481 blast edge to closest point of blast	109	1.21	0.77
Edge of old failure zone to closest point of blast	366	4.08	2.43
Shortest distance from failure crest from closest point of blast	415	4.62	15.47
Furthest distance to crest along projected shear zone from closest point of blast	598	6.66	18.74

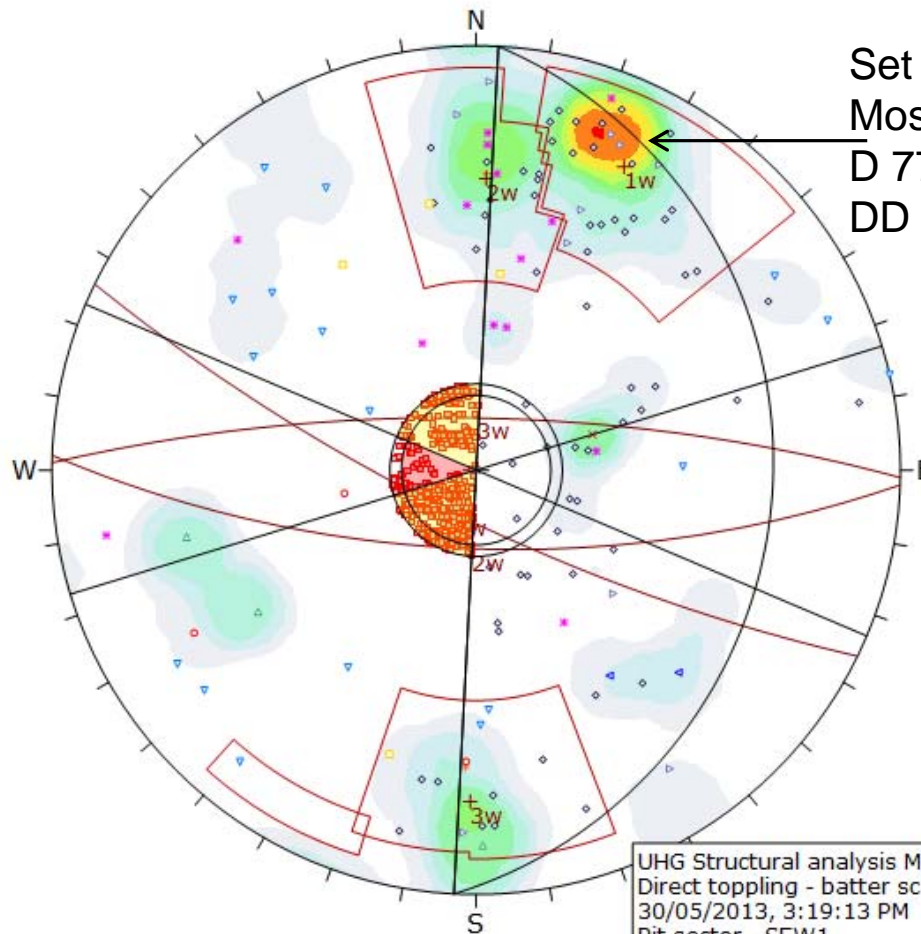
# Discontinuities

## Data Collection

- Geological structure mapping by geology team (major structure and boundary fault zones)
- Detailed structural data collected manually for each pit sector and analysed with Dips 6.0 (Dips analysis mostly for determining batter angles but also for slope scale analysis of bedding planes)
  - locality and RL
  - dip and dip direction, structure type
  - host rock type and strength, weathering
  - roughness large scale and roughness small scale, JRC, persistence
  - water
- Limited Sirovision work done – site plans to introduce the system next year
  - Identification of bedding plane shears likely to be difficult with Sirovision (or any other remote mapping method)
  - Manual mapping and identification of shears and marking them before Sirovision shots is a possible solution

# Dips Analysis Example

S Endwall Sector SEW1 (Characterised by Steeply Dipping and Folded Strata)



Set 1  
Mostly BP  
D 77°  
DD 206°

Symbol	TYPE	Quantity
◇	BP	132
×	BPS	10
△	F	30
+	FA	20
▽	JSP	34
○	MU	12
◇	MS	20
○	SH	9
▷	SPL	30
◇	SZ	42
	Others	94

Symbol	Feature
◇	Critical Intersection

Color	Density Concentrations
	0.00 - 1.10
	1.10 - 2.20
	2.20 - 3.30
	3.30 - 4.40
	4.40 - 5.50
	5.50 - 6.60
	6.60 - 7.70
	7.70 - 8.80
	8.80 - 9.90
	9.90 - 11.00

Maximum Density	10.03%
Contour Data	Pole Vectors
Contour Distribution	Fisher
Counting Circle Size	1.0%

Kinematic Analysis	Direct Toppling
Slope Dip	20
Slope Dip Direction	93
Friction Angle	23°
Lateral Limits	20°

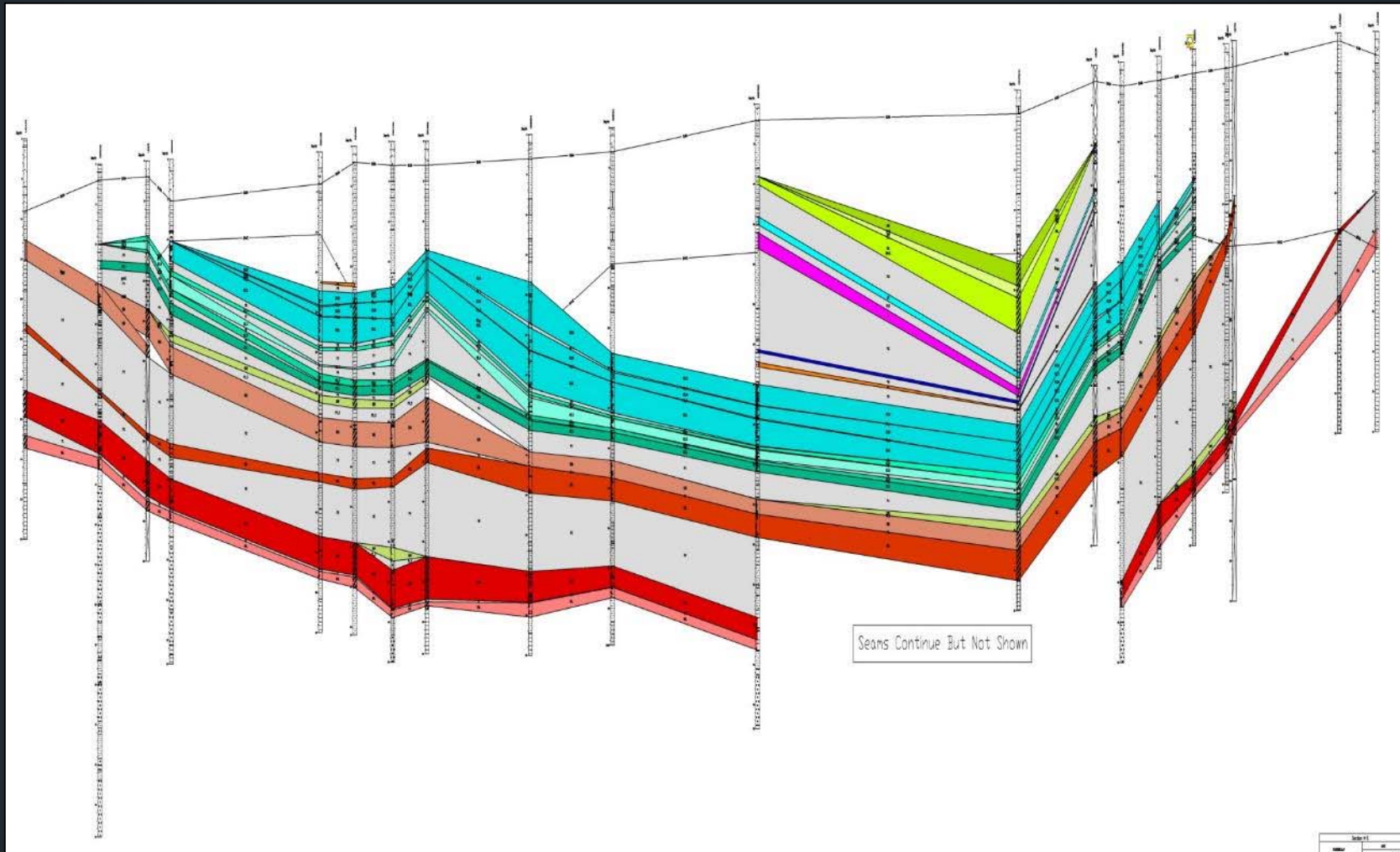
UHG Structural analysis May 2013  
Direct toppling - batter scale  
30/05/2013, 3:19:13 PM  
Pit sector - SEW1  
Sub Sector - N-S

	Critical	Total	%
Direct Toppling (Intersection)	237	92846	0.26%
Oblique Toppling (Intersection)	3352	92846	3.61%
Base Plane (All)	2	433	0.46%

# Discontinuities – Responses

- Formation of site geotechnical team
- Geotechnical hazard plan produced by site geotechnical engineers coupled with hazard reports
- Training – site personnel trained to recognise signs of instability such as: cracking along crests and ramps, loose dribbling rock on faces, shears and faults
- Geological model referred to extensively during design process. Most useful information being:
  - Depth of weathering profile
  - Seam ply correlation cross sections (these do not show faulting but trace seam continuity)
  - Seismic cross sections (extensive seismic survey carried out for future mining area) mainly used to identify major structures (faults) as well as likely strata dips
- Determination of realistic material properties for discontinuities:
  - Referred to published papers, AMC experience, laboratory tests
  - Collection of physical characteristics in the field
  - Limit equilibrium back-analysis (Galena) of existing failures
- Batter angles determined using Dips. Endwalls – temp 40° to 45° and final 30° to 45°. Highwalls 60°.

# Typical Seam Ply Correlation Cross Section



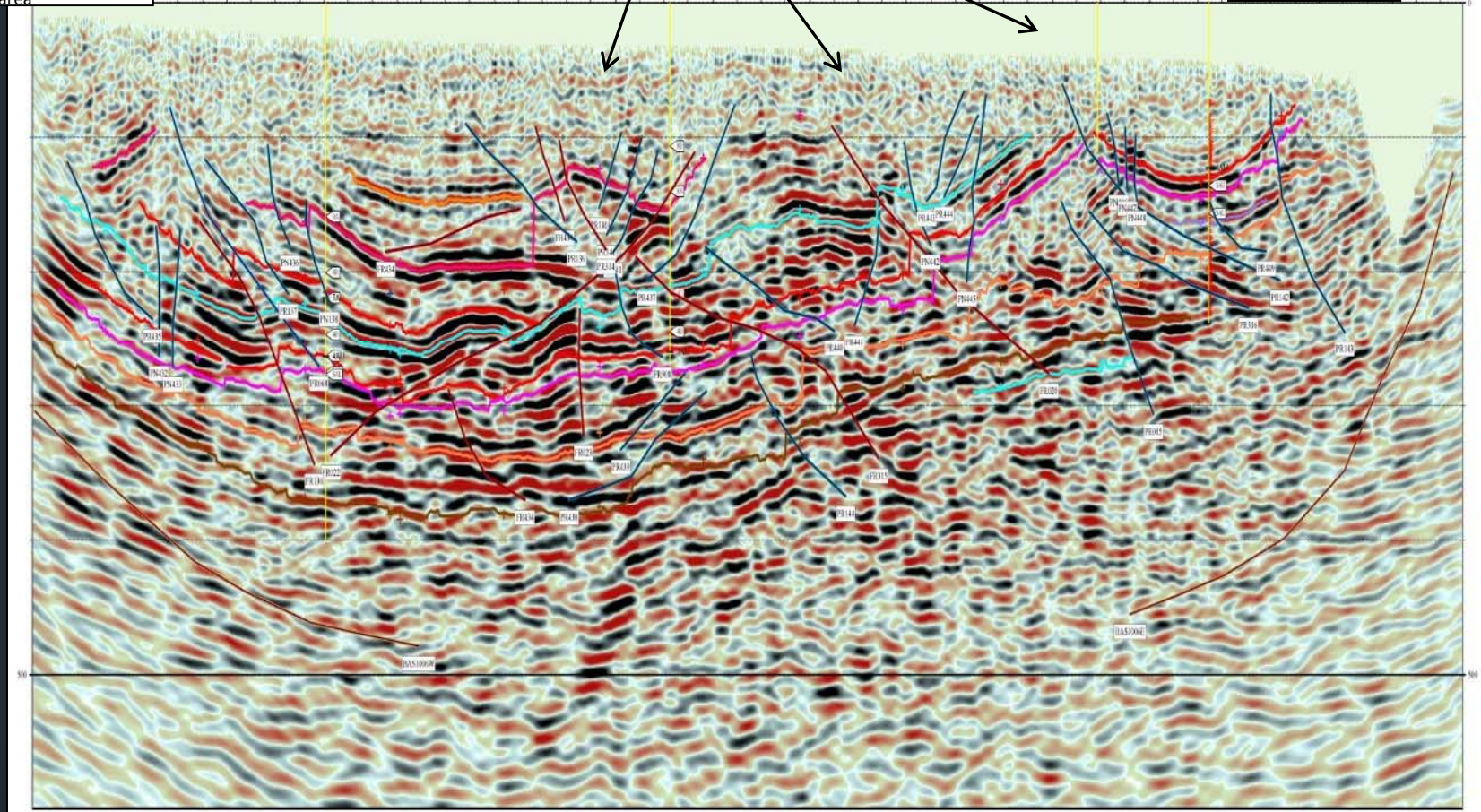
# Seismic Cross Section Example

LHG SEISMIC SURVEYS 2010-2011  
REVISED JULY 2012 - LINE 10-06

Southern boundary fault area

Disturbed zones

Northern boundary fault

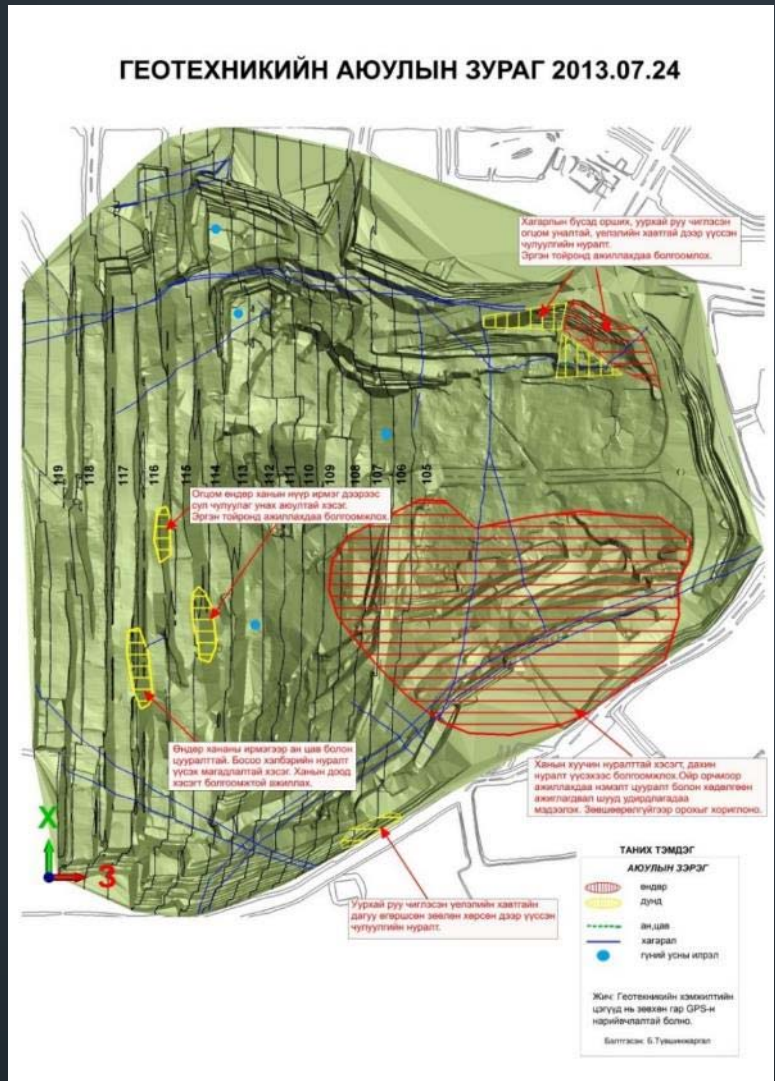


# Rock Strength Table

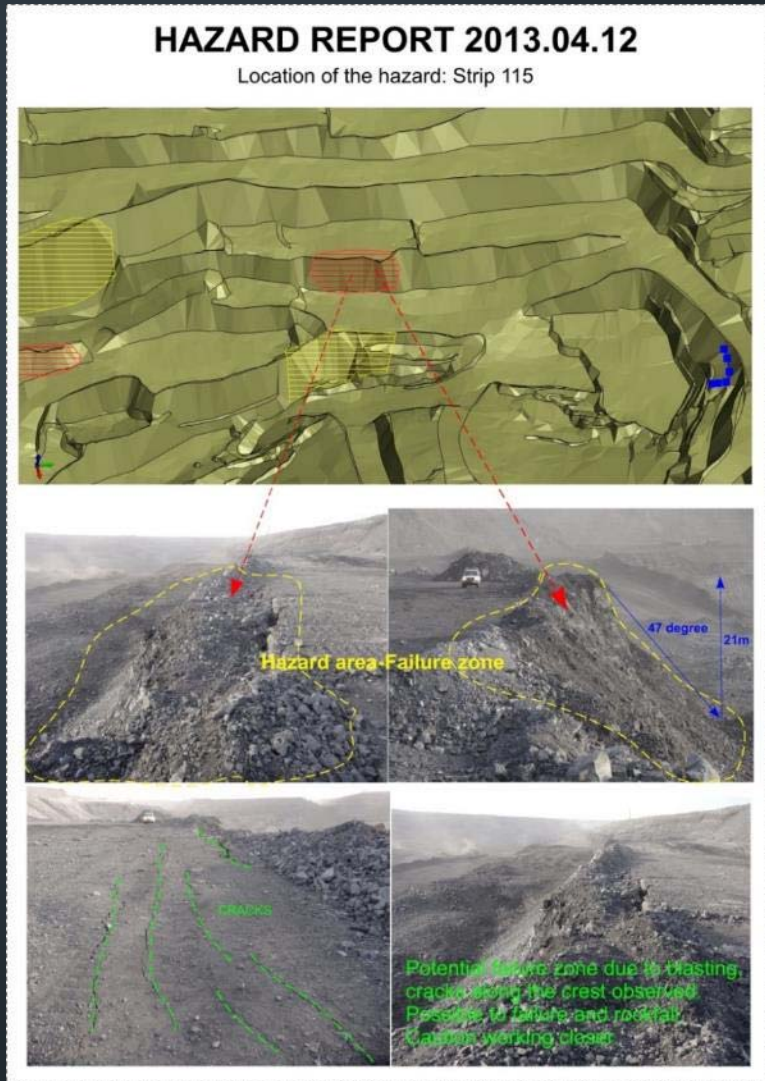
Geotechnical Domain	Unit Weight (kN/m <sup>3</sup> )	Cohesion kPa)	Friction Angle (°)	Method by Which Determined	UCS (MPa)	Geological Strength Index (GSI)
Weathered overburden	22	35	19.2	Back analysis and closest fit in RocData	7	30
Moderately weathered overburden	23	126	30	RocData estimation	14	50
Fresh Overburden (siltstone and mudstone)	25	283	37.5	RocData estimation based on site observations, BN rock tests and literature	30	56
Coal (fresh)	15.2	34	25.6	RocData estimation based on site observations, BN rock tests and literature	7	35
Coal (sheared)	14	17	18.5	Back analysis and closest fit in RocData	3	20
Bedding plane shears	18	1.5	13	Back analysis	–	–
Blasted rock	21	76	35	Estimated from value for waste material with large fragments (Simmons and Simpson, 2006)	–	–
Major faults and shear zones	20	25	18.6	Estimated using RocData	23	20

# Risk Management

Hazard plan (example)



Hazard report (example)



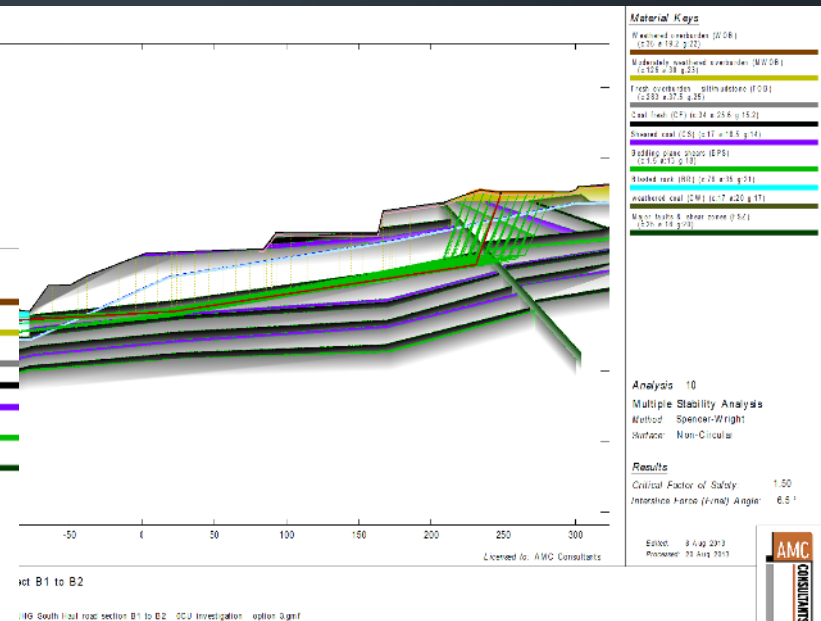
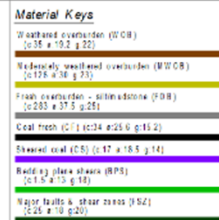
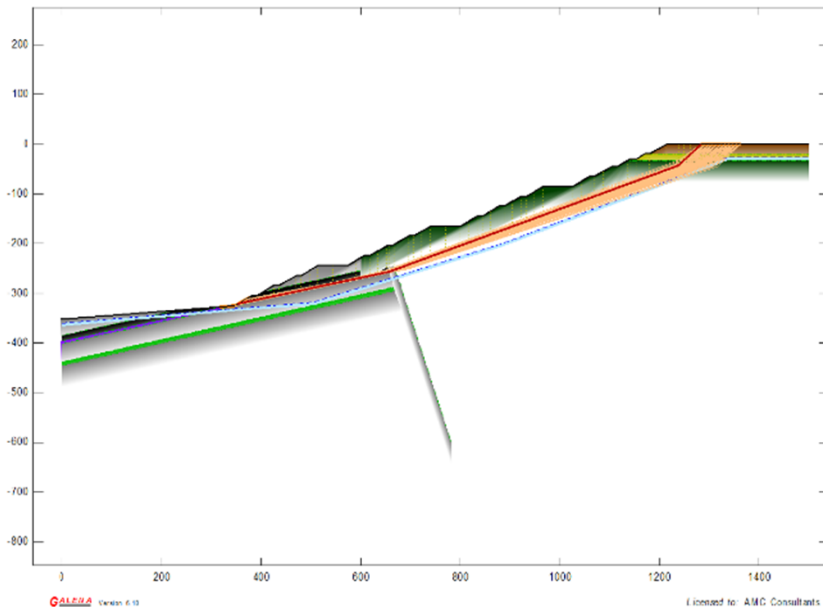


# Galena Models

Difference between simplified and detailed versions

Detailed geometry  
Strip scale ( $\pm 100\text{m}$  spacing)

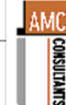
Simplified geometry  
Pit sector scale (2 or 3 in 1.5 to 2.5km)



Analysis 1  
Multiple Stability Analysis  
Method: Spencer-Wright  
Surface: Non-Circular

Results  
Critical Factor of Safety: 1.07  
Interstice Force (Fint) Angle: 18.3°

Edited: 20 Jun 2013  
Processed: 20 Jun 2013



# Responses – contd.

- Extensive limit equilibrium (Galena) analyses for both long term slope design (simplified structure) and short term planning and layout assessments (detailed structure).
- Overriding feature determining slope angles was found to be bedding plane shears (verified by running circular and non-circular potential failure analyses). Non-circular consistently had lower FOS than circular except where slope consists of weathered overburden or wide faulted zones where circular was dominant.
- Endwalls generally have low overall slope angles ( $22^{\circ}$  to  $30^{\circ}$ ) due to steeply dipping coal seams along flanks.
- At lower strata dip angles (i.e.  $5^{\circ} < \text{dip} < 15^{\circ}$ ) FOS in excess of 1.2 only possible with additional stabilising work e.g. buffer blasting (softwall blasting).
- Cross over point where seam dip  $<$  OSA and seam dip  $>$  OSA is about  $15^{\circ}$
- Over  $15^{\circ}$  dip endwalls developed along dip with berms every 50 m vertically to reduce chance of slab buckling (OSA works out about  $2^{\circ}$  less than dip)

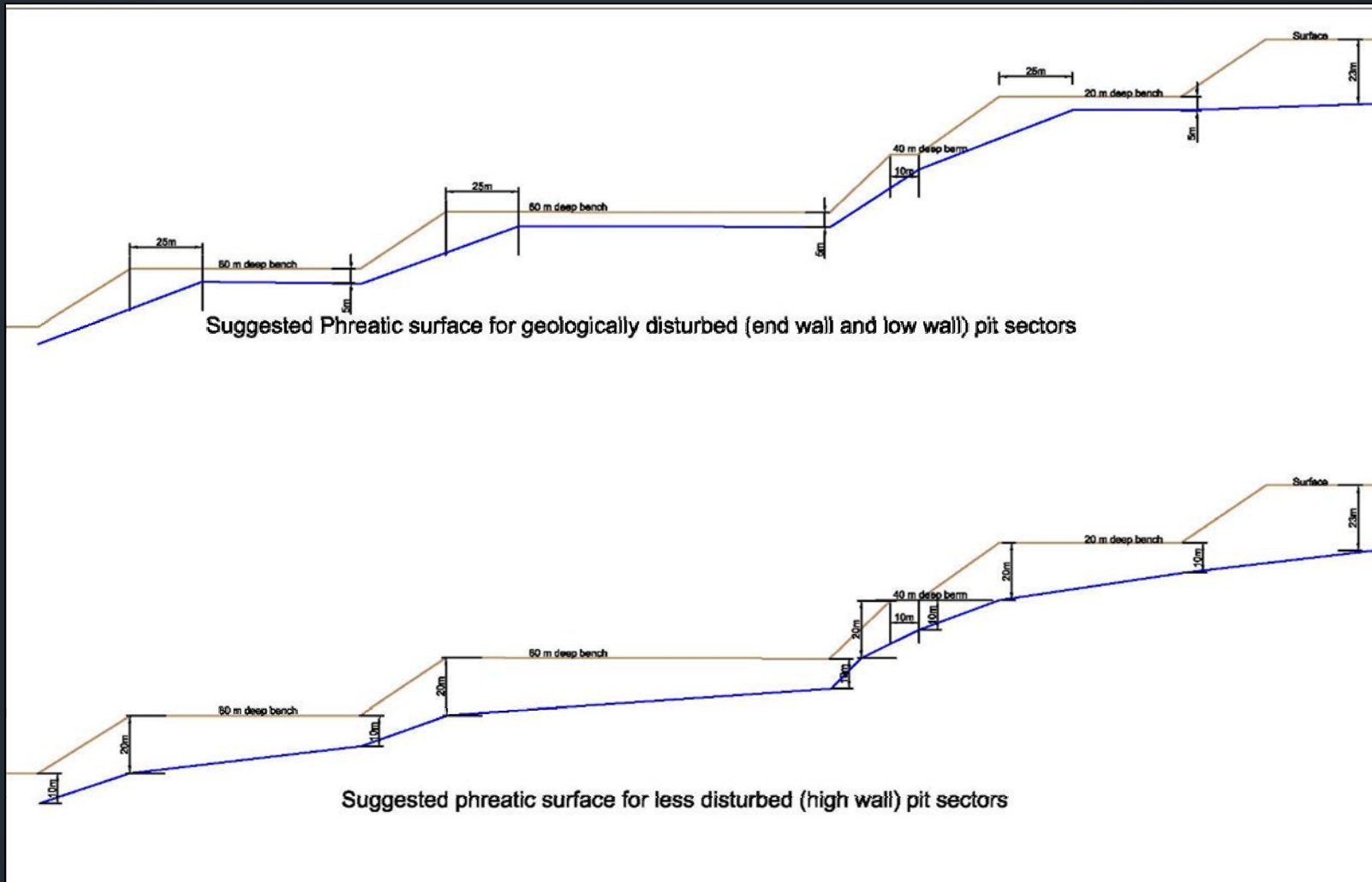
# Responses – contd.

- Detailed Galena models assessed to determine strata dip boundaries for TARP hazard zones in the range 0 to 15°.
  - $\leq 5^\circ$  code green
  - $> 5^\circ$  and  $\leq 7^\circ$  code orange
  - $> 7^\circ$  code red
- Endwall slope design criteria:
  - Overall slope min FOS 1.2 and slopes beneath ramps FOS 1.25
  - Peak particle velocities are managed in blast designs – current limit 100 mm/sec
- Monitoring by means of: visual inspection, total station prism surveys (daily pickups by geotech team) and rudimentary crack meters (daily readings)
- TARP triggers set for the following:
  - Observed conditions
    - Tension cracks
    - Slippage along bedding planes
    - Opening or displacement along fault planes
    - Structure strike
    - Floor heave
    - Rainfall
  - Monitored movement e.g.  $>100$  mm/day trigger to go up to code orange

# Geohydrology

- Generally dry but water associated with structural corridors
- Damp areas used as an aid to identifying structurally disturbed areas
- Actual position of phreatic surface can make a big difference in limit equilibrium analysis
- In-pit water level data gathered by geotechs by dipping selected blast holes
- Generic phreatic surface model used in Galena models – will be updated later in 2013

# Generic Phreatic Surface Model



# Risk Management

- UHG has a ground stability management plan (GSMP) and is audited annually on compliance
- GSMP currently being split into Geotechnical Design Document and PHMP following follow-up major risk assessment



# Geotechnical Team

(since early 2012)

- Senior Site Geotechnical Engineer
- Two Site Geotechnical Engineer
- All site geotech activities, mapping, logging, hazard plans, hazard reports, liaison with mining department, monitoring, training operators
- Principal Geotechnical Engineer (AMC) remote assistance, quarterly visits and mentoring



# Geotechnical Training

- Senior Site Geotechnical Engineer (Engineering Geology Degree – Cuba) given 3 months intensive training at AMC’s Brisbane office and subsequent mentoring
- Senior Site Geotechnical Engineer and Site Geotechnical Engineers mentored during site visits by Principal Geotech Engineer as well as remotely when required
- Senior Site Geotechnical Engineer produced and presented Mongolian language strata control course for operator level personnel
- Supervisory training material in process of being prepared

# Baruun Naran Mine (BN) (Satellite Pit)

BN West pit view



BN East pit view



# Background and History

- First exploration work done by a Mongolian/Russian team in 1983
- Detailed exploration work done by the QGX Mongol LLC in 2005
- Khangad Exploration LLC acquired the BN deposit in 2008
- Khangad Exploration LLC completed an exploration program a period from 2009-2012
- Mining started from January, 2012
- Currently limited production from BN due to general coal export climate

# Locality

Location of the Baruun Naran deposit



# Locality

- BN property is located in Omnogobi aimag of southern Mongolia, approximately 500 km south of Ulaanbaatar, the capital of Mongolia
- The town of Dalanzadgad, the provincial capital, is located 61 km to the west of the property
- BN deposit is located 30 km west from the UHG mine site

# Infrastructure

- Workers ger camp (8 km from the mine site)
- A 30 km sealed two lane highway from BN mine to UHG mine site
- Workshop
- Office building
- Laboratory

# Ger Camp

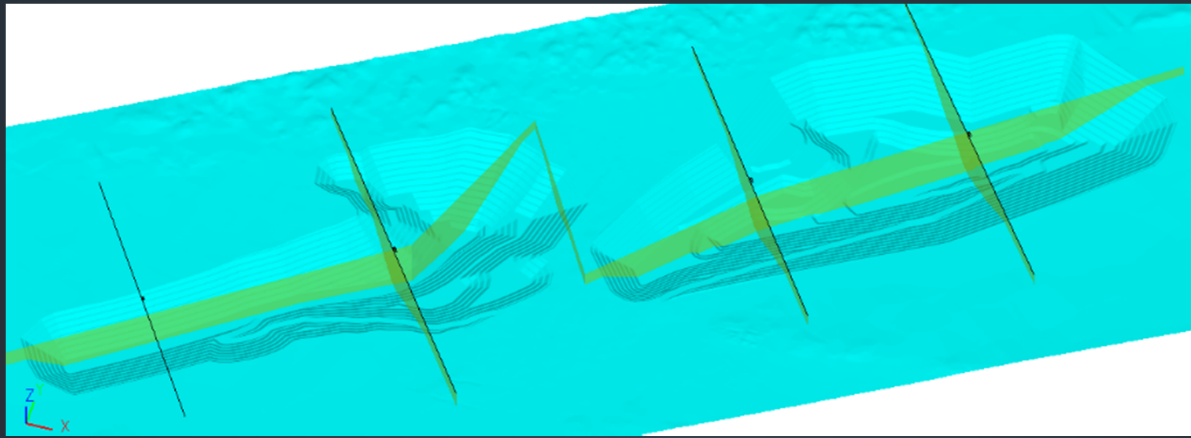


# Equipment Inventory

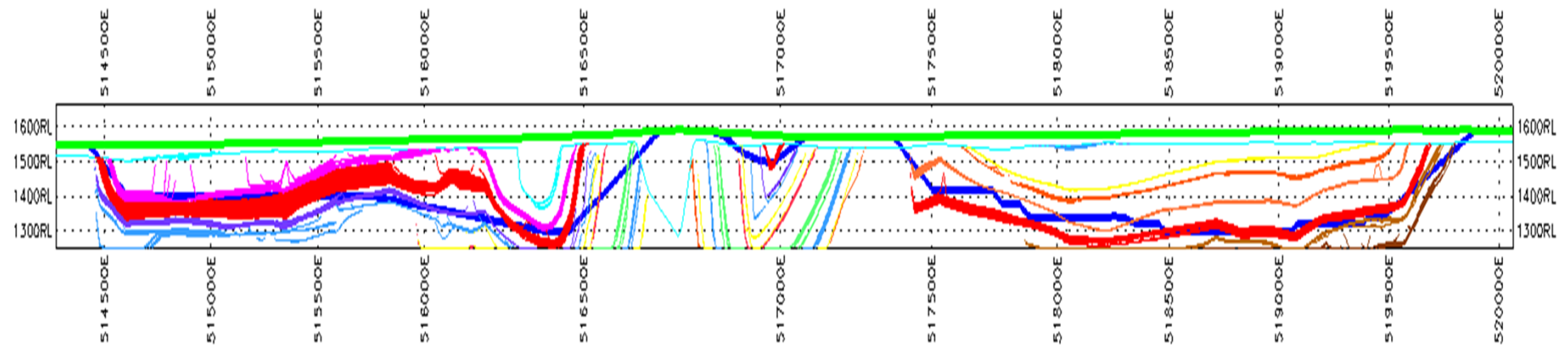
Type	No
<b>Excavator</b>	
Cat 390D	1
<b>Grader</b>	
Cat 14H	1
<b>Dozer</b>	
Cat D8R	1
<b>Water truck</b>	
Nissan	1
<b>Haul trucks</b>	
Cat 773F	3

# Coal Seams

BN West and East cross sections views

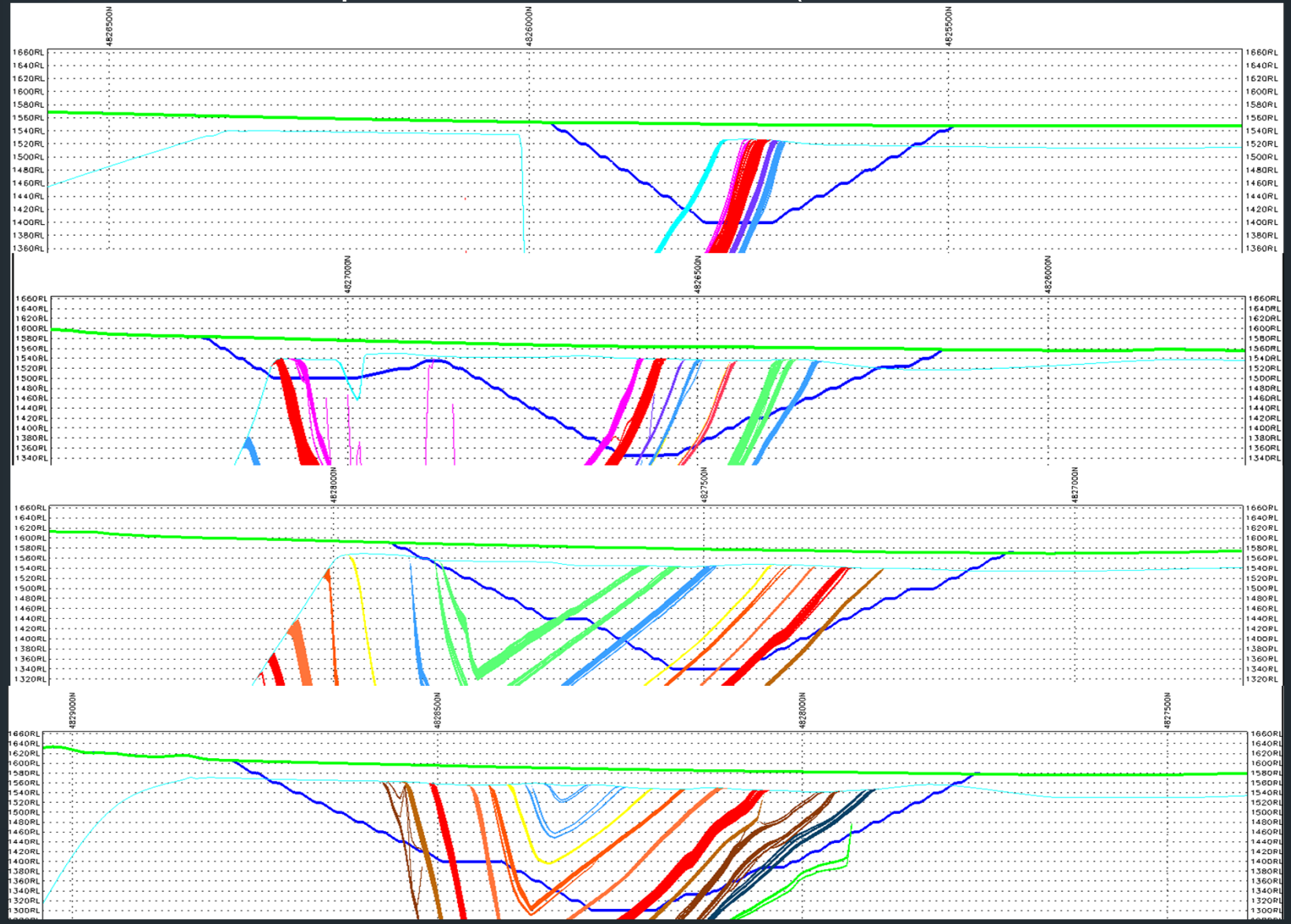


EW cross section view



# Coal Seams

BN West and East pit cross sections views (from West to East direction)



# Geological Structure

- Major syncline feature with southern limb (low wall) dipping  $35^{\circ}$  to  $70^{\circ}$  and northern limb (high wall) dipping  $70^{\circ}$  to  $90^{\circ}$ .
- Extreme dip of seams is the main challenge faulting is not such a big issue.
- Seams generally mined along strike with each strip exposed along dip.
- Due to the severe folding there are many bedding plane shears mostly within the coal seams.

# Mining of Steeply Dipping Seams



# Rock Mass Strength

- Limited available data but of good quality
- Same limitations for lab work as at UHG
- Use the same rock strength table as UHG for design work

# Discontinuities

- Structural data gathered for each pit sector and analysed with Dips – mainly for batter slope angle determination
- Structural data also used as one input in determination of OSA especially in the highwall where seams dip into the pitwall
- JRC and continuity data collected

# Slope Failure

Failure along  
bedding  
close behind  
face



# BN Pit



# Major Geotechnical Challenges

- Steeply dipping seams mainly developing along dip (high wall)
- Long exposures of steeply dipping seams pose likely problems due to slab buckling
- Main Failure modes:
  - circular failure in weathered overburden – particularly earlier slopes mined  $>65^\circ$
  - shear planes dipping shallower than the seams and cutting through the coal strata
  - planar failure along bedding planes a short distance into and parallel with the face
  - loose slabs dropping out due to weaker underlying mudstones self-mining

# Solutions

- Low wall slopes designed parallel to seam dip with berms to reduce OSA to less than seam dip
- To reduce slab buckling for interim pit walls – design with max 20 m high benches. Additional analysis planned (Phase<sup>2</sup>).
- Hazard plan mapping and training
- BN to be included in new geotech design Document and PHMP



# Acknowledgements

Thanks to the management of Mongolian Mining Corporation for permission to produce this presentation