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Wednesday 30 May, 2012

Mining and Industry Projects
NSW Department of Planning & Infrastructure
GPO Box 39
Sydney NSW 2001

email: plan_comment@planning.nsw.gov.au

Dear Sir/Madam,

Re: Submission as an Objection - Coalpac Consolidation Project: Application No: 10_0178

The Colong Foundation for Wilderness requests that requests that this submission be read in association with the submissions by the Blue Mountains Conservation Society and the Lithgow Environment Group. Each submission has however focused on different but complementary aspect of the proposal.

The proposed expansion of open-cut coal mining so as to consolidate two smaller existing open-cut coal mining operations should be refused development consent, as it is inappropriately located too close to the village of Cullen Bullen and largely within a public forest of high conservation value.

The proponent, Coalpac, will effectively alienate over 750 hectares of Ben Bullen State Forest for its exclusive occupation under various mining leases for a period of 21 years. During that 21 year period of occupation, a unique and diverse natural landscape will be destroyed. The subsequent rehabilitation measures will not restore the biodiversity, geodiversity and scenic values lost by open-cut mining.

Rehabilitation will instead create a biologically depauperate, fragile and unstable landform; a human artefact, prone to erosion and further degradation. The rehabilitation proposed for the areas mined by open-cut methods cannot restore near-surface groundwater levels and the stream flows dependent upon them. Any remaining surface waters and groundwater that discharge from the project area will be highly contaminated with metal salts, particularly iron and manganese. These discharges may also be acidic.

In addition to the coal extracted, the 422 million cubic metres of rock and earth spoil created by this mining proposal would fill four-fifths of the volume of Sydney Harbour. A *sydharb* is 500 million cubic metres (see - http://en.wikipedia.org/wiki/Port_Jackson#History; 422/500 = 0.844 or 84% of a *sydharb*. *Sydharbs* are an Australian unit for large volumes usually of water but in this case it assists us in conceptualising the amount of the waste rock generated by the Coalpac proposal. This volume is also the equivalent of 168,800 Olympic swimming pools of rock waste, there being 200,000 Olympic swimming pools to the *sydharb*)).

The Colong Foundation supports the NSW National Parks and Wildlife Service's wish to add the entire Ben Bullen State Forest to the conservation reserve system as a matter of priority, as it is an area with outstanding natural values.

This is a destructive coal mining proposal that should be refused development consent in order to prevent inferior, relatively high polluting coal being mined in a manner that would needlessly destroy important natural heritage and damage the health of residents living in Cullen Bullen.

The proposed open-cut mining would, if approved, set the precedent of open-cut mining along the western facing slopes of the Great Dividing Range to within 50 metres of the pagoda studded sandstone cliff lines. If this sort of mining were to be proposed in the Capertee Valley, the Hartley Valley or the Wolgan Valley, a spontaneous public protest would arise from the influential middle classes that would see such proposals rejected, and perhaps even prevent development applications being lodged. The only difference between those proposals and this current open-cut proposal is that the protestors from Cullen Bullen are less well connected.

There are other superior coal resources that could be mined in preference to these remnant resources. These resources are found in a location distant from settlement areas and can be obtained by underground mining methods. Further, less damaging underground coal mining methods also could be pursued to obtain the last remnants of coal under Ben Bullen State Forest. Underground mining occurs to the north, south and east of the proposal.

Coalpac asserts that lower impact underground mining methods are not viable. The determining authority should keep in mind that these methods that are apparently only not viable in this proposed project area, were paradoxically viable in all the areas previously mined by underground methods both within and adjoining the project. Such underground methods would be compatible with reservation of the Gardens of Stone Stage 2 proposal. The proposed open-cut mining, however, is incompatible with either concurrent or subsequent reservation of the Gardens of Stone proposal under the *National Parks and Wildlife Act, 1974*.

POOR PROJECT: A REMNANT COAL DEPOSIT UNSUITABLE FOR FURTHER DEVELOPMENT

The majority of the scenic Ben Bullen State Forest of high conservation value has been subjected to coal mining by underground methods by the former Baal Bone Colliery to the north, the former Wallerawang Colliery to the south, as well as the former Ivanhoe Colliery. In the project proposal area are found the former Invincible, Old Invincible and Tyldesley Collieries. These mines removed by underground mining methods a considerable part of the original coal body within the project area and also in coal deposits to the east of the project area in the case of the Invincible Colliery.

The area that is the subject of this proposal is by and large being subjected to an environmental double jeopardy. This coal mine proposal is not then a sequential land use, where heritage values will be protected, but where heritage values previously retained by less intensive mining methods will now be destroyed. This double jeopardy mining is not Ecological Sustainable Development, it is an unethical intensification of mining methods that destroys the natural heritage values of the forest.

Underground coal mining methods employ many more people and are less destructive that open-cut methods. Contrary to Coalpac's assertions of economic gloom and employment doom, any plans to undertake further open-cut mining in the state forests of the Western Coalfield will mark a decline in regional social and environmental welfare. Such mining will be at the expense of less intensive mining methods.

The project justification in the environmental assessment favours development of the remnant coal resources by open-cut mining methods, presenting economic and employment arguments. In fact, the cost of NOT developing this coal resource in the manner proposed is nearly zero (and perhaps negative), as substitute coal resources of better quality are located nearby and to the north along the Mudgee railway line. Refusal of this environmentally unsound proposal would increase employment as coal resources would be developed by underground methods with less environmental damage to satisfy the coal needs of the local power stations. This, in fact, was the case until recently.

Before Coalpac commenced open-cut operations in 2006, it was the underground mines that provided the coal requirements for the Mt Piper and Wallerawang Power Stations. The continued stability of supply for the operation of the Delta Electricity owned power stations can be and has been ensured by underground coal mines, including those large mines operated by Centennial Coal.

Angus Place Colliery production increased from 2.3 to 3.5 million tpa in 2006 and to 4 million tpa in 2010. Springvale Colliery produces 3.5 mtpa of coal. Airly Colliery came into production in 2011 with the production of 0.5 million tpa of coal. These mines can provide good substitute coal resources if this proposal is refused consent. Surely these mines would prefer to provide coal to a local market, than to go to the expense of exporting the resource. There are also other underground mines that could also provide coal to meet this local demand.

The mining workforce arising from any increase in underground mining in the region to supply power station needs would increase the supply of goods and services to the community. At the same time environmental impacts would decrease relative to the damage caused by open-cut operations.

OPEN-CUT MINING METHODS POORLY JUSTIFIED

The proposed coal resource is dirty and requires considerable processing to obtain an inferior high ash coal (14 to 30% ash). The resource in the project area is a cumbersome cluster of thin coal seams interspersed between four-fifths of a *sydharb* of waste rock. The 108.5 Mt of raw coal proposed to be produced by the mining produces 71.2 Mt of thermal coal product (Appendix G, page 108, Table 12.7), suggesting the poor quality raw coal will generate double the amount of reject, estimated in the main report as 15.2Mt (Volume 1, Table 9, page 45). An examination of the coal face in the mine pit for the Invincible Colliery suggests that this higher estimate for dirt, rock and ash seems correct. The coal seams are half dirt and rock.

There is a direct relationship between fossil fuel mining intensity and adverse environmental impacts. When coal extraction is maximised through open-cut methods, the environmental impacts of production are also maximised. There are many situations where maximising coal extraction is inappropriate, including in the Ben Bullen State Forest which is a key part of an Office of Environment and Heritage's proposal for a State Conservation Area.

The arbiters for this development proposal should consider whether the adverse consequences of an approval that would maximise coal production are excessive, and if lower intensity mining is not possible, then whether it would be best to refuse consent to stop the potential damage. The claim that this particular coal resource is essential is unfounded, not only because local substitute resources exist, but because half or less of the known coal resources in NSW will ever be developed.

In addition to local adverse impacts, there are global, cumulative and longer term contexts to this proposal. Without proper consideration of this larger context, the cumulative impact of many similar coal mining approvals around the globe will mean that life on earth will not survive far into the next century.

As the decision-makers for this proposal would appreciate, Australia's fossil energy resources are expected to last for many decades, if not centuries at the projected rates of production. NSW has over 12 billion tonnes of recoverable coal reserves. The proportion of economic demonstrated reserves (EDR) to current production for Australia is estimated at 90 years for black coal, 63 years for conventional gas and 100 years for coal seam methane (Energy in Australia, 2010, pgs 4 and 5). The total reserves of coal and gas are at least an order of magnitude greater than the economically proven resources and recoverable reserves already identified by exploration.

Those determining fossil fuel proposals, including this one, should adopt a policy of permanently sequestering the carbon embodied in coal resources. Keeping carbon in the ground is the best way to prevent climate change disaster.

Given the very large extent of Australia's coal and gas resources, the arbiters of coal mining proposals should 'sterilise carbon-based energy resources', right now, to provide for the necessary environmental protection and social welfare measures that local communities, like the Cullen Bullen community are demanding. As previously stated, there are more than ample alternative coal deposits to exploit before society must transition to more sustainable energy resources and survive.

A gradual transition towards ending fossil fuel use by 'resource sterilisation' is a pragmatic means to overcome mining and energy industry inertia in addressing climate change. It will shorten the time taken to transition to more sustainable resources and reduce the environmental damage caused before the transition is achieved.

Society can well afford to be far more particular about where and how its coal resources are developed, omitting those inferior resources and environmentally damaging development proposals.

For example, when a remnant inferior coal resource is buried within 4/5 of a sydharb of waste, it is only possible to economically mine such lower-density energy resources because the price for diesel fuel is too low. In the absence of a realistic fuel price, through the removal of subsidies and tax-concessions, development control is the next most logical mechanism to stop such damaging coal mines.

Decision-makers should 'ear mark' 50 per cent of the entire coal and gas resource in each NSW coalfield for the protection that farmers and conservationists seek, as doing so will not harm the economy. These 'ear marked' fossil fuels will never be needed in a future society that must survive by taking action to avoid catastrophic climate change. Once the transition is made, the coal left in the ground is irrelevant.

Government and decision-makers will be condemning future generations to living with a climate disaster, unless bold decisions are made to permanently sequester coal. As development consents run for a 21 year period, changes to development control policy regarding sequestering coal need to occur now.

The mining industry is opposed to an increase in environmental protection standards (ACIL Tasman, March 2011, for the Minerals Council). The Minerals Council argues that further environment protection (labelled 'restrictive policies') has a significant adverse impact on the NSW economy. In fact, mining companies can well afford much greater environmental protection as mining companies are making huge profits.

In the last twenty years the mining industry has had a high degree of success in convincing regulatory authorities and politicians to take risks in the management of natural resources. The coal industry successfully rebranded risk management as 'taking risks with the environment', inverting the precautionary principle. An entire school of thought has developed that justifies this form of risk taking, the equivalent of economic deregulation. Such deregulation won't cause a GFC, it could instead achieve the ultimate demonstration of its cleverness, the end of life on earth.

Risk taking to maximise profit at the expense of environmental management has also resulted in high impact coal mining proposals being opposed by many local communities across NSW.

EXCESSIVE GREENHOUSE GAS EMISSIONS

The scale of the greenhouse gas pollution that will be generated by this proposal confirms the opinion that this low density, dirty coal resource variously inter-bedded with rocks and dirt is a highly inferior resource.

Dr Haydn Washington in his submission has identified a hundred-fold error in the greenhouse gas assessment. “The Coalpac emissions are 7 million tonnes CO2 a year (rounded off from 6.989 Mt on p. 109 of App G). 7 Mt is 0.007 Gt and this is 0.02% of world emissions not 0.0003 %” (Dr Washington, 20/4/2012).

Dr Washington goes on to state that “Australia’s carbon footprint is 546.3 Mt C02e (Aust. Nat. Greenhouse Accounts, Dec 2011) so 7 Mt is 1.3% of Australia’s total carbon footprint”. . The proposed mining requires excessive amounts of energy to extract and clean the coal to a useable condition. These proposed coal resources are inferior. Upon combustion they generate significant amounts of greenhouse gases, as well as consuming large amounts of high-quality energy (diesel and electricity) during the proposed mining operation.

PROPOSAL DRIVEN BY A NEED TO MAXIMISE SALE PRICE, NOT MINING PRACTICALITIES

The Australian reported on the 28th October, 2010 that the Invincible and Cullen Valley mines are for sale. This complex proposal seeks to maximise the sale price.

The mining may only be viable under certain market conditions. Diesel fuel and other energy resources may need to be relatively cheap and tax deductible to ensure viability of this proposal. The long-term viability of mining these resources is not a consideration for the seller.

POORLY JUSTIFIED ENVIRONMENTAL AND SOCIAL IMPACTS

The proposed high-impact, open-cut coal extraction is not acceptable environmentally or socially.

Open-cut coal mining is incompatible with the sustainable use of high conservation value areas, as groundwater, streams, native landforms and their dependent ecosystems, cannot survive once the sedimentary rocks are blasted to smithereens with high explosives and torn apart by huge coal mining machines. To assert otherwise is hypocrisy.

In an earlier era, improvements in social welfare from coal mining in the project area were achieved by the previous low-intensity mining operations. It will not be the case with this intensive mining proposal. To mine the very last coal from under the west-facing slopes of the Great Dividing Range will set a precedent of open-cut mining in the Gardens of Stone that the local community considers should not be made. There is nothing optimal about the proposed mining. The optimal amount of coal mining in this state forest was exceeded when open-cut mining commenced at the Invincible Colliery in September 2006.

Representations made to NSW Parliament by the Cullen Bullen community are a clear signal that decision-makers must not take risks with community health and the protection of living natural resources in the Ben Bullen State Forest. It is time to restore some balance in resource development and start to prepare for the future by refusing development consent for such an inferior coal mining proposal. For example, the community does not want further scarring of the landscape by the open-cut mining, such as along the Castlereagh Highway.

Coal mining by lower impact, underground methods has taken place in the Ben Bullen State Forest for over 100 years. The forest has already played its fair part in the energy economy of NSW, it’s time to retire (sequester) the remaining coal resources in this state forest in order to protect the community and the environment from undue injury.

Open-cut mining is inconsistent with the NSW Forestry Act, 1916

The Ben Bullen State Forest was set aside in perpetuity under the *Forestry Act, 1916* for conservation and sustainable use of all its resources. The clearing and mining proposed is incompatible with the *Forestry Act, 1916.* The proposed clearing and subsequent open-cut mining of this forest will cause the destruction of the recreational, silvicultural and ecological values of this public asset.

The Colong Foundation for Wilderness submits that the proposed Coalpac Consolidation Project is inconsistent with the *Forestry Act, 1916* and that it is specifically incompatible with the objects of the Forestry Commission set down in s8A. That section states that:

> *(1) The objects of the Commission shall be:*
>
> *(a) to conserve and utilise the timber on Crown-timber lands and land owned by the commission or otherwise under its control or management to the best advantage of the State,*
>
> *(b) to provide adequate supplies of timber from Crown-timber lands and land owned by the commission or otherwise under its control or management for building, commercial, industrial, agricultural, mining and domestic purposes,*
>
> *(c) to preserve and improve, in accordance with good forestry practice, the soil resources and water catchment capabilities of Crown-timber lands and land owned by the commission or otherwise under its control or management,*
>
> *(d) to encourage the use of timber derived from trees grown in the State,*
>
> *(e) consistent with the use of State forests for the purposes of forestry and of flora reserves for the preservation of the native flora thereon:*
>
> *(i) to promote and encourage their use as a recreation, and*
>
> *(ii) to conserve birds and animals thereon, and*
>
> *(f) to provide natural resource environmental services (whether within or outside of New South Wales).*

The proposal will effectively privatise a public asset for private gain under the assertion that coal development is in the best interests of the people of NSW. The proposal would effectively alienate and destroy a major part of Ben Bullen State Forest without due process. 752 hectares of the Ben Bullen State Forest will be destroyed if this proposal is approved. Legislation to revoke this part of the forest should pass through the NSW Parliament before any part of the forest is destroyed. The *Forestry Act 1916* is clearly intended to protect state forests, and no mining should take place that destroys a state forest. As the proponent does intend to destroy part of the state forest, the environmental assessment is deficient for not proposing forest revocation.

The proposed open-cut mining to may be acceptable in 'indifferent' country, but not in the high conservation value Gardens of Stone reserve proposal. Here, in the 843 hectares to be destroyed by open-cut mining; the 500 or more native plant species that are set within a natural rock garden landscape formed by internationally significant 'pagodas' clustered along this part of the Great Dividing Range and Ben Bullen Range will be lost. Such high species richness and unique geodiversity should not be destroyed to extract a remnant of poor quality, high ash, thermal coal buried within almost a *sydharb* of useless rock.

Open-cut mining too close to Cullen Bullen

Both the Cullen Bullen residents and the National Party of NSW do not consider this proposal to be socially acceptable due to its location beside Cullen Bullen.

A petition opposing the mine contains 251 signatures, with **120 signatures from Cullen Bullen** (population 198 in 2006); 99 from elsewhere in the Lithgow Local Government area and only 32 from outside the Local Government Area[i].

The Cullen Bullen, village population has declined from 209 persons in 2001 to 198 persons in 2006, whilst being surrounded by six coal mines. This rural community has shrunk while coal mining operations have grown around it, possibly as a response to associated mining and health impacts.

The evidence from the United States on health impacts indicates that coalmining communities in West Virginia had an increased risk for developing cardiopulmonary disease, chronic obstructive pulmonary disease (COPD), hypertension, other lung diseases and kidney disease. Mortality rates for these diseases were higher in coalmining areas compared with non-mining areas of the region[ii]. In the case of blasting associated with coal mining, the typical concentrations of NOx in post blast clouds can measure anywhere between 5.6 to 580 parts per million, exceeding the safe limits by around 30 to 3000 times[iii]. The proposed project may also see further spontaneous combustion of exposed coal waste material and cause greater air pollution for the local community and travellers on the Castlereagh Highway.

As the decision-makers for this proposal would be aware, the Central Council Natural Resources and Energy Policy Committee of the National Party of Australia (NSW) in its submission to the NSW Government's draft Strategic Land Use Strategy requested a 5km buffer zone between towns and villages and open-cut coal mining[iv].

When considered together, the National's policy and the 60% of Cullen Bullen residents who signed the petition make a strong case that the proposed open-cut coal mining activities will not be acceptable when it is so close to a community.

The proposed Coalpac Integration Project boundary is less than 500 metres from the centre of Cullen Bullen. The village is already being negatively impacted by blasting and dust from Coalpac's open-cut mining activity. Threats to the health of children attending Cullen Bullen Public School due to the open-cut mining are a public health concern. Blasting may damage properties and nitrous oxides could impact on community health in Cullen Bullen. The town's depressed property values would continue indefinitely as the town would become surrounded by degraded land and dust would make it difficult to keep property clean.

In line with National Party policy, a 5km buffer zone excluding open-cut mining should be established around the town of Cullen Bullen and its Primary School to protect their health, social values and amenity. As this makes the proposal unviable, it should be refused development consent.

OPEN-CUT REHABILITATION MEASURES INADEQUATE FOR AREAS WITH HIGH PLANT DIVERSITY

Rehabilitation methods for open-cut coal mines are incapable of restoring the original biodiversity and geodiversity of the Gardens of Stone Reserve Proposal.

Appendix J of Appendix J reviews the performance of the existing rehabilitation and is prefaced with the following limitation: "*The native vegetation communities in the surrounding lands has favoured specific geologies and hydrological preferences over very long periods of time (eons), and the preparation of the rehabilitation sites after mining is unlikely to support entirely consistent landforms. As such the complexity derived from native vegetation remnant can only be an indicative target.*" In more direct language, the areas rehabilitated after open-cut mining have no chance of matching the complexity and diversity of the original native ecosystems.

The Colong Foundation draws to the determining authority's attention that Appendix J of Appendix J does not compare the rehabilitation areas with those native ecosystems that were lost when mined. The proponent does not have pre-mining assessments of biological diversity for the mined areas from which to ascertain rehabilitation performance. The benchmarks used do not obtain an accurate measure of lost botanical diversity. Assessment of other communities or sites that were not mined can only give an approximate guide.

The targets for species diversity in Appendix J of Appendix J are based on a baseline generated from the examination of **just two undisturbed reference sites located nearby**. The very poor sampling of just two reference sites means that pre-mining plant diversity has been grossly underestimated. In any case the restoration does not even restore half the original diversity of these two small reference sites. If properly assessed, the actual biological diversity of the rehabilitated areas is likely to be far less than these estimates.

The Foundation notes that plant species diversity for the rehabilitation sites declines in the oldest age class (year 2002). An alternative explanation to that given for this observed decline may be that the acacia over storey in the oldest age class has begun to die off, with adverse consequences for species diversity. The Colong Foundation is concerned that when the acacia over storey of the rehabilitation areas does die off, aggressive, declared noxious weeds will take over, including St John's Wort and Scotch Broom already present on these rehabilitation areas. Both these weeds have a capacity to invade undisturbed adjoining native ecosystems and replace them. Within the life of the proposed project, both the rehabilitated and surrounding state forest areas will become weed infested, degraded landscapes.

Further, Coalpac does not to use a sterile grass in its rehabilitation program. The use of sterile grasses in rehabilitation is standard practice for mine rehabilitation. The grass used is spreading east into the Ben Bullen State Forest (Gardens of Stone reserve proposal) including the previously pristine pagoda shrubland complex areas.

Grass used in rehabilitation in the Pagoda complex community
within project boundary, Ben Bullen State Forest (I. Brown, 21 Dec, 2010)

Adverse Aesthetic Impacts

The mining activity will devastate the landscape and spectacular scenery of the Ben Bullen State Forest that forms the scenic backdrop to the Castlereagh Highway. The scenic assessment in the environmental assessment did not properly consider the visual impact from the Highway, and is in consequence deficient.

The Invincible Colliery Open-cut Mine initial approval of 7th September 2006 came with a Coalpac Pty Ltd's assurance that "*the open cut operations proposed would not be visible from the Castlereagh Highway due to the intervening topography and existing vegetation coverage*" (Refer: 05_0065_proponents_response_to_submissions page 4, para 2, NSW Planning Website). The steep open-cuts into the escarpment of Ben Bullen State Forest are clearly visible along a 2 km section of the Castlereagh Hwy, from the top of the Great Dividing Range west nearly to Cullen Bullen township. Such a history of behaviour does not give a sceptical local community confidence in Coalpac's statement of commitments in this environmental assessment.

The proposed level of destruction of the recreational and ecological values in Ben Bullen State Forest fronting both sides of the Castlereagh Highway appears to be little moderated in this current proposal from the damage shown below.

This image from September 2011 of the Invincible open-cut shows how views were blighted along the Castlereagh Highway. The Coalpac consolidation proposal will ruin similar views north of Cullen Bullen that represent the western gateway to the Greater Blue Mountains World Heritage Area.

<u>The proposed biodiversity off-set areas are unacceptable</u>

The conservation off-set areas on farmland planted out with tube-stock as well as the open cut areas now rehabilitated will have a very small fraction of the species richness of the intact native woodland communities in the Ben Bullen State Forest.

The environmental assessment fails to provide adequate or accurate information on the proposed offsets to enable a genuine assessment of their values to be made. The environmental assessment refers to "*Eucalyptus Cannoni* potential habitat" and these areas in the offset properties are shown as dark green, omitting to clearly indicate these are currently cleared areas of native pasture. The environmental assessment does not provide data on the amount of cleared land within its proposed offset properties. The result of these offset areas will be similar to that shown in the figure below.

Planting *Eucalyptus cannonii* seedling 'tubestock' on cleared farmland does not replant the woodland ecosystems destroyed by open cut coal mining, or hide the open cut highwall from the Castlereagh Highway. (Photo: K. Evans, 2010)

The remainder of the Hillcroft, Yarran View and Hillcroft/Billabong properties proposed as biodiversity offsets appear to have been grazed. From the documentation it is impossible to determine how much of the off-set properties are in a poor condition, with erosion and weeds, or poor quality habitat. The existing offset properties are also mostly cleared land, and it is not stated how much of the existing offset is cleared and how much of that cleared land has been replanted.

There is to be $23 million spent for funding offset properties. It appears that at least half of these funds could be more or less wasted on replanting cleared lands with native species. Any biodiversity offset strategy that offers revegetation of cleared land is a poor use of proposed offset funds.

The environmental assessment notes "that environmental offsets, as a minimum, [should] be commensurate with the magnitude of the impacts of the development and ideally deliver outcomes that are '*like for like*'" (Hansen Bailey emphasis, page 198). The proposal to replant cleared land with threatened plants does not create habitat that replaces undisturbed native ecosystems.

The Nature Conservation Council of NSW has a policy of opposing the use of offset systems in the management of native vegetation. This policy is also the policy of its over hundred member groups (including the Colong Foundation). Offsets systems are driven by development not the conservation of native vegetation. Offset systems result ultimately in a 'net loss' of biodiversity and extant high quality remnant native vegetation. Further, the NCC policy opposes offsets that facilitate further broad-scale clearing of intact, remnant native vegetation in return for revegetation of other areas.

Conserving or planting low quality vegetation cannot compensate for losses of high quality vegetation. Replanted vegetation in an offset is a poor substitute for the natural complexity of the remnant vegetation that has been cleared, ultimately resulting in net loss of biodiversity and ecosystem services.

All of the area proposed to be cleared for the open-cut coal mine is high quality native remnant vegetation. It sustains an impressive array of life including at least 19 different plant communities; more than 500 native plant species; at least 86 bird species; at least 29 mammal species; at least 14 reptile species; at least 8 frog species; and countless invertebrates.

Rare and threatened biota are also well represented: 2 endangered ecological communities (totalling at least 18.5 hectares to be cleared); critically endangered grassy Box Gum Woodlands; threatened Geebung habitat; 19,200 vulnerable *Eucalyptus cannonii* trees in 278 hectares of native forest; at least 8 bird species; at least 4 mammal species; at least one reptile; more than 30 plants; and many other threatened species potentially occur.

The ancient eucalypt forests and woodlands support many grand specimens of a variety of tree species, including Brittle Gum, Brown Barrel, Ribbon Gum, Broad-leaved Peppermint and Inland Scribbly Gum. These mature forests are rich in tree hollows providing homes for the many species of bats, mammals and birds mentioned above to nest and roost. Such diversity once destroyed cannot be replaced by offsets.

<u>Native flora and fauna surveys incomplete and deficient</u>

Despite undertaking eight field surveys before lodging this Environmental Assessment at least 100 native plants were missed (see the submission by the Lithgow Environment Group for the list of native species omitted by Coalpac consultants).

The environmental assessment also omitted the Broad-headed snake (V) that I observed, photographed Tuesday 22nd December, 2010 and reported to the EPBC referrals section. The record was also reported as a threatened species by Mr Ian Brown as follows: Broad-headed snake *Hoplocephalus bungaroides,* date: 21-12-10 and 27-12-10 (species seen at same location on both dates); location: GDA94 Zone 56H 22653.630968 (8931-3N Cullen Bullen); altitude: 1080m; tenure: State Forest (Ben Bullen); habitat: beside small rock hole on flank of large bare sandstone outcrop (pagoda) on edge of plateau. The snake is in the area proposed for highwall mining.

Broad-headed Snake photographed on a pagoda in the project area (K. Muir, Dec 2010)

<u>Adverse impacts on pagoda landscapes</u>

This very high biological diversity is further enhanced by being set within a landscape of great geodiversity and scenic value. Washington and Wray in their 2011 paper 'The Geoheritage and Geomorphology of the Sandstone Pagodas of the North-western Blue Mountains Region' report that platy pagodas are an ‘uncommon and significant geomorphic landscape feature, and are distinguished by the extent and regularity of their ironstone banding,’ (*Proceedings of the Linnean Society of New South Wales 132, 131-143*: Attachment A).

The authors are ‘not aware of any other rock formations in Australia or overseas that mimic the geomorphology of platy pagodas’ that are ‘distinct and significant geomorphological features, even by world standards’ (Washington and Wray, pg 141).

Much of the core pagoda area is located outside protected areas, principally on Newnes Plateau and in Ben Bullen State Forest. The authors are concerned that the scenic, cultural and geoheritage values of the pagoda landscapes have not been officially recognised and conclude that the platy pagodas ‘deserve full and expanded recognition as a significant part of the geodiversity and geoheritage of the Blue Mountains region’ (Washington and Wray, pg 142).

The environmental assessment makes only passing reference to pagodas. The full extent of pagoda formations in the project area is not accurately mapped in the environmental assessment.

Pagoda formations will not be protected by the proposed 50 metre set-back from open-cut mining and the 100 metre monitoring zone. There is no adequate control of vibration from blasting, as blasting will occur up to 50 metres from the pagodas and cliff lines. The mine void being so close to the cliffs and pagodas may increase the stresses and vibration movement from blasting due to reduced lateral support.

The accumulative subsidence from highwall operation in each of the seven coal seams mined may cause far greater subsidence damage, such as pagoda cracking and collapse. Such mining will surely have more than 2cm of subsidence movement attributable to the mining of one seam. More conventional underground mining of any sort would be prohibited along cliff lines, particularly in scenicly prominent pagoda areas where highwall mining is being proposed.

Only 3% of the coal resource is proposed to be extracted by highwall mining, less than 1.9 Mt in total. Highwall mining is inherently dangerous to workers, and should not be attempted in such a scenic and geomorphologically unstable area.

Instead of the proposed 50 metre set back and highwall extraction of coal from under pagodas, open-cut operations should not be allowed to intrude into the gullies below the Great Dividing Range and the Ben Bullen Range. Open-cut mining should not occur on any of the Ranges’ steep the slopes which are too steep to be effectively rehabilitated.

Pagodas on the Great Dividing Range, within the Coalpac project boundary
where highwall mining is proposed (K. Muir, Dec 2010)

INTENSIFICATION OF MINING OPERATIONS UPON APPROVAL

Coalpac's proposal seeks to wind back the environmental protection embodied in its existing development consent. The proposal seeks to replace areas approved for highwall underground mining with an approval for open cut mining over the same area.

The arrangement of highwalls was defined by the Development Consent issued by the then Minister for Planning, The Hon Kristina Keneally, on the 4th of December 2008. The consent also contained a figure defining the proposed final landform and the consent was slightly modified on 12th January 2009 and again on 8th October 2010.

In effect the proposal seeks to overturn the previous consent in relation to mining operations and final landform in the following manner. Figure 1 of the development consent of 12 August 2009 (Appendix A) would be replaced by Figure 6 on page 35 of the Environmental Assessment by Hansen Bailey.

This variation would see new areas under the pagoda complexes subjected to highwall mining. The Environmental Assessment notes on page 106 that stresses in rock structure have the 'ability to affect stability of pillar sidewalls, roof and floor'. It would appear that these areas should not be subject to highwall mining at all, to preserve the stability of coal pillars in the old workings.

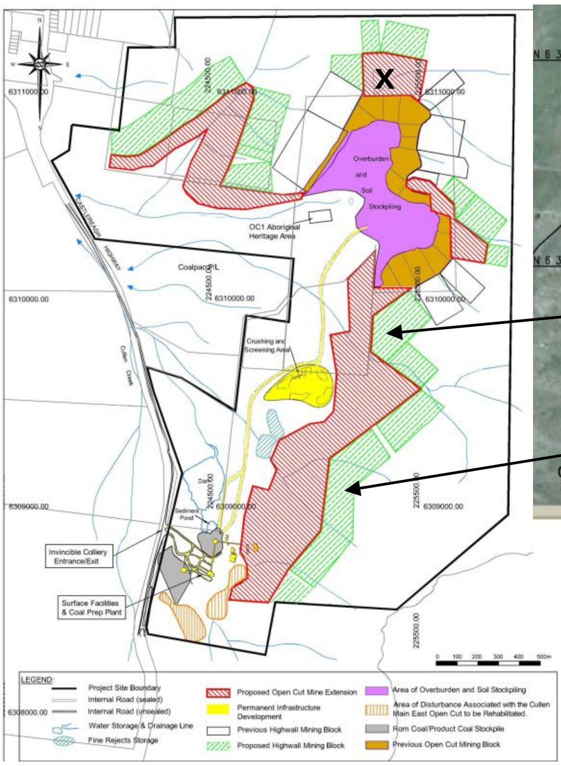
Further, the area that was to be subject to highwall mining in the previous development consent is now proposed to be subject to open cut mining instead. This moves the open-cut mining proposal into the steeply sloping land below the Great Dividing Range.

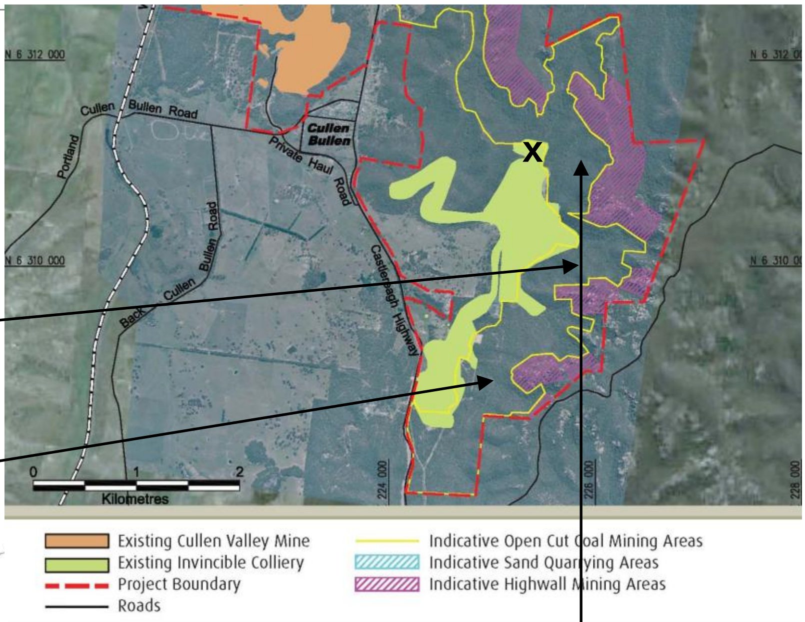
Mr Bret Leisemann, Chief Development Officer of Coalpac stated at a meeting in the Colong Foundation office on Wednesday 15th December, 2010 that open cuts in this current proposed action would have highwall faces up to "100 metres high" and that all faces would be completely filled during rehabilitation. These highwalls are about four times higher than those currently approved and higher than a twenty storey building.

Any rehabilitation that seeks to backfill open-cut highwalls to 100 metres high would prove very difficult to shape to slopes of 14 degrees or less for the Invincible Colliery or 18 degrees or less for the Cullen Valley Colliery. Such steep slopes will not support adequate topsoil cover or revegetation, particularly on the drier west-facing slopes.

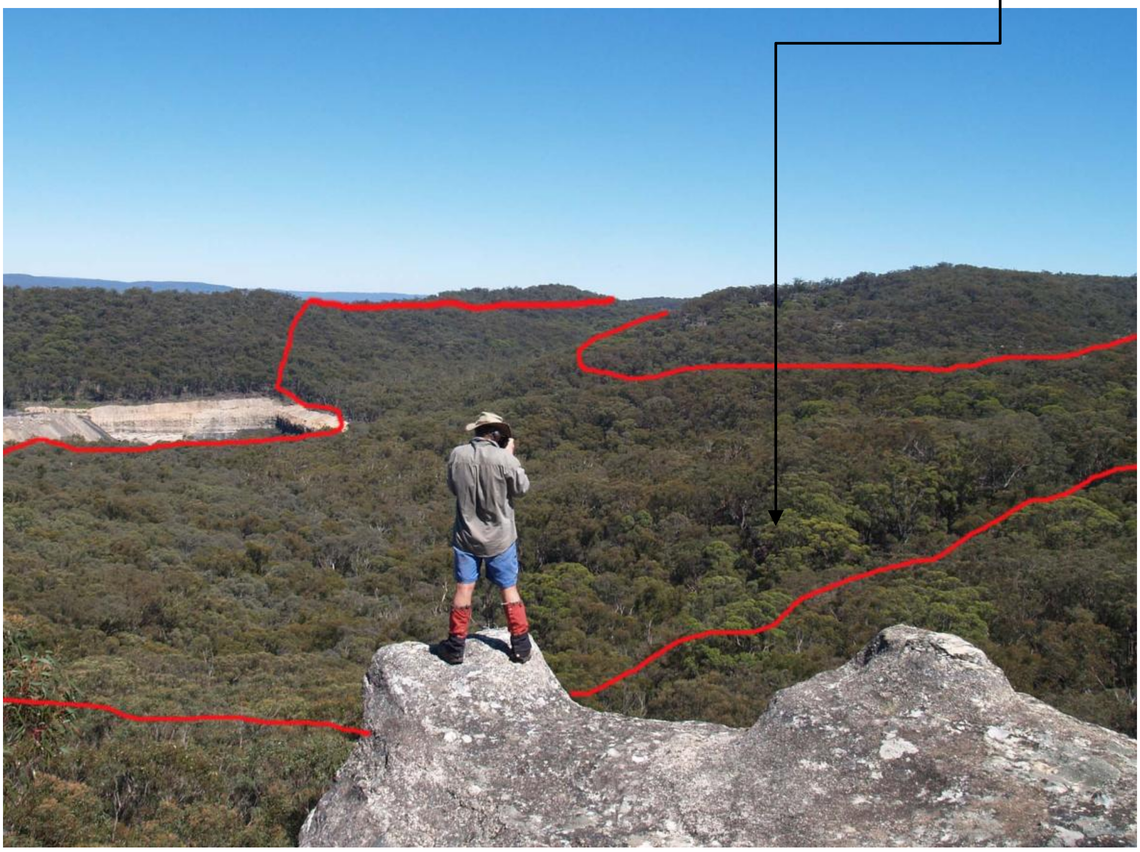
The proposed fill depth of up to 100 metres will settle over time, with the result of isolating the pagoda areas and their wildlife with surrounding degraded lands. Future mining modifications, however, could remove these retained highwall areas in another round of mining intensification.

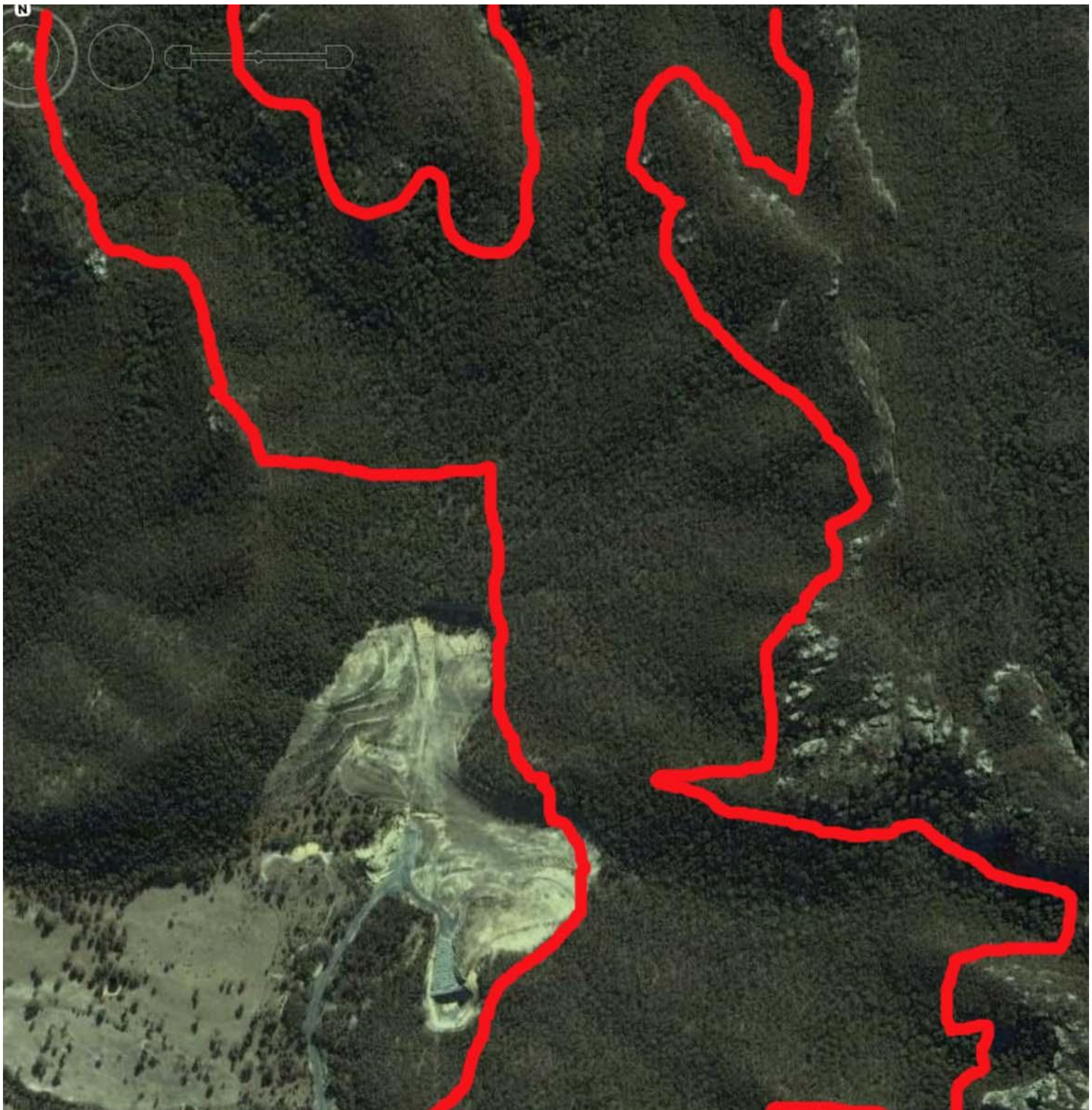
An example of the current open-cut highwall at the Invincible Colliery located by an "X'' in the figures on the following page (I. Brown Dec 2010).





The approved highwall mining area (left, in green) is now **proposed to be open-cut** (right, lying between the two yellow lines). The image below reveals the extent of forest what could be mined open-cut. (K. Muir, Dec 2010)





Google image showing the proximity of the proposed open cut to pagoda complexes on the Great Dividing Range. (Google image, 2006)

The steep western face of the Cullen Valley open-cut cannot be adequately backfilled and rehabilitated. The proposed mining of steep slopes also will not be adequately backfilled or rehabilitated (Feb 2010)

THE WATER MANAGEMENT SYSTEM IS POORLY EXPLAINED AND NOT JUSTIFIED

The Colong Foundation for Wilderness is concerned that eco-toxic groundwater effluent will be discharged from the former Invincible underground mines to enable the proposed open-cut mining to extract the coal pillars in the Lithgow Seam from these old mine workings. The Foundation appreciates that Coalpac has given assurances that it will not mine the old mine workings.

Licensed Discharge Point 001 (LDP001) for Invincible Colliery, however, can discharge eco-toxic mine effluent from the 6,245ML stored in old workings into Long Swamp in the headwaters of the Coxs River. The Colong Foundation requests that LDP 001 be removed from the Environmental Pollution Licence 1095 to prevent further damaging effluent discharges at the 2ML/day rate allowed. Further, the request for a licence for LDP 001 under part 5 of the Water Act should be refused by the Office of Water.

This swamp meets the definition of a Temperate Highland Peat Swamp an endangered ecological community under the Commonwealth *Environment Protection and Biodiversity Conservation Act, 1998*. Long Swamp has been degraded in the past by the discharge of highly polluted water being pumped from the abandoned Invincible underground mine workings.

LDP001 – the results of saline, metal rich, Invincible Colliery effluent discharge into an arm of Long Swamp near the headwaters of the Coxs River.

The surface waters of the Gardens of Stone are naturally very low in salinity (typically 30 S/cm). At its source near Ben Bullen, the Coxs River salinity rests at 30 S/cm (Jonkers, 2009). The high salinity of mine effluent will significantly impact these aquatic and riparian ecosystems that have evolved naturally under very low nutrient conditions.

The discharge from LDP001 was observed in the latter half of 2007 to have a salinity ranging from 1600 – 1750 µS/cm (Jonkers, 2009). The saline effluent water from the underground workings flowed into a western branch of Long Swamp and then into the headwaters of the Coxs River. These discharges would have severely damage the ecology of Long Swamp but have ceased for the time being, however, the licensed discharge point has been retained.

The immediate effects of increased salinity on inundated native swamp vegetation include stunted growth, and leaf burn and drop, leading to plant death. In less severe cases, germination is suppressed by salinity, which can be broad scale downstream of the discharge point. Local native plant populations decline and native plant diversity changes as indigenous plants are replaced with more adaptable and salt tolerant plant varieties. Loss of native vegetation compounds the salinity problem by producing soil exposure, known as soil scalding, and erosion.

The determining authority should not assume that State Environmental Planning Policy (Sydney Drinking Water Catchment) 2011 will guarantee adequate water treatment. The SEPP, being an environmental planning instrument, only operates to regulate mining proposals and not mining operations.

When consideration of water management and water quality triggers is deferred by the development consent and another approval is required for say a water management plan, the issue of that secondary approval doesn't need to apply the neutral or beneficial test to eco-toxic mine effluent. The SEPP will not apply after development consent. The determining authority should be careful not delegate approval to the EPA of a water management plan to be prepared at a later date unless the consent requires application of the neutral and beneficial test to water discharges.

Further, the eco-toxic effluent discharges at a rate of 4.25ML/day still continue from the now decommissioned Baal Bone Colliery. This pumping lowers groundwater levels in the interconnected Invincible and Old Invincible workings that are an unstated part of this open-cut proposal. These discharges damage Jews Creek Swamp and should also cease to be licensed.

The groundwater impact assessment and water balance assumes continued discharge via the Baal Bone Colliery (page 46, Appendix O). Without pumping, it will not be possible to access the coal pillars in the abandoned workings of the Old Invincible and Invincible Collieries. The water levels in the old underground workings for the Baal Bone, Invincible and Old Invincible collieries are to be kept low to permit mining of the Lithgow Seam within the proposed open-cut mine.

These workings should instead become flooded, so as to reinstate near-surface groundwater levels. None of the Lithgow Seam coal pillars in the old workings should be extracted by this proposal so that eco-toxic discharges into the EEC-quality Temperate Highland Peat Swamps on the Coxs River and Jews Creek can be terminated.

Discharge point for the heavily mineralised Baal Bone
Colliery effluent (Photo: K. Muir, March, 2009)

Much of the analysis on hydraulic connectivity between the old mines and Baal Bone Colliery in Appendix O seems to be a flight of imagination. Figure 39, page 164 of Volume One of the Environmental Assessment clearly indicates that these mines, with the exception of the Tyldesley Colliery, are directly interconnected. The location of Invincible LDP001 in Figure 39 confirms this hydraulic connection. Note also that the Environmental Assessment states that "the elevated water levels within LD001 may represent an area with a higher recharge rate resulting from fracturing above the longwall panels" (page 165). These panels are in the Baal Bone Colliery and establish the hydraulic connection to the north.

From an examination of Figure 39, the Colong Foundation concludes that analysis of seepage rates in Appendix O is both misleading and incorrect. Coalpac could through a subsequent development application use existing Baal Bone LDs (and perhaps also the Invincible DL001).

The claim that "dry mining conditions will still mostly prevail for the proposed Project" (page 64, Appendix O) remains true only if Baal Bone Colliery continues to dewater its underground mine workings at a rate of 4.25ML/day. The Environmental Assessment is misleading regarding the need for water licensing and incomplete in relation to water management.

No consideration of a neutral or beneficial test for these discharges has been considered in relation to LD001. No proposal has been made to treat these discharges.

INSUFFICIENT INFORMATION PROVIDED FOR THE SAND MINE WITHIN A COAL MINE PROPOSAL

The proposed sand mining operation is a novel idea that would prevent effective rehabilitation of the northern part of the Cullen Valley open-cut. It is proposed to obtain 5 million cubic metres of sand by crushing the acid-generating Marangaroo Sandstone found underneath the Lithgow Coal Seam.

The amount of water, 4 to 5 thousand litres per cubic metre of sand seems excessive, as does the need to wash the sand twice to obtain a sellable product. This may be due to the fact that the sand will come from a sandstone with considerable capacity to generate acid. Perhaps also this is why the water is proposed to be disposed of down the abandoned Tyldesley Colliery. The sand is being obtained from unweathered sandstone. Like the coal mining proposals, the amount of energy required to mine this sand deposit will be relatively high when compared to other sand mining operations.

Such an activity is usually the subject of a detailed environmental assessment in its own right, but is given only cursory attention in the five large volumes dedicated almost entirely to the coal mining proposal. The claim that the waste from the sand mining is inert is contradicted by the amount of sulphur found in the Marangaroo Sandstone. This sandstone has 0.82% sulphur and is likely to cause acid mine drainage. Any sand product with residual sulphur will be unusable.

The sand mine proposal is highly speculative, with little information as to the nature of the resource mined, except that it contains sulphur. Usually such proposals have a detailed assessment of the potential sand product, whether it produces well graded sand or not, whether the grains are rounded, the proportion of quartz in the sand, and how much silt and clay factions are present in the sandstone. None of these data are provided about the alleged sand product.

Further, the operation of the proposed sand mine would interfere with the normal sequential rehabilitation of the proposed northern section of the Cullen Valley open-cut coal mine.

Sand mining from unweathered sandstone that then requires haulage by truck over the Blue Mountains to the Sydney construction materials market should not be approved. The proposed truck movements, 128 truck movements a day to move 0.64Mtpa of sand, will be through the residential suburbs of the Blue Mountains. The truck transport Appendix Q mentions haulage by

B-doubles, which are banned on the Great Western Highway. The economics of the proposal may not be viable with smaller trucks that are allowed to pass through the Blue Mountains.

The ten or so pages dedicated to this sand mining proposal are insufficient to justify it. All the data on sand mining is throughout the body and appendices of the environmental assessment and is so poorly presented as to almost defy the consideration such a proposal deserves.

The sand mine proposal appears to be more about increasing the sale price of the Coalpac proposal than any real intention to provide construction sand.

ENVIRONMENTAL RECORD OF THE PROPONENT

Cape Broom is spreading in the Coalpac lease areas and non-sterile grasses are being used to stabilise the rehabilitation areas. Use of an invasive grass in rehabilitation repeats a serious mistake made many times in mine rehabilitation.

On 23 March 2007, Coalpac lodged an application to vary their Protection of Environment Operations (POEO) Licence Number 1095, to recommence discharging up to 4 ML/day of mine water from their borehole in Ben Bullen State Forest (LDP001). The licence variation was approved, and pumping commenced in June 2007 for eco-toxic mine effluent with a salinity ranging from 1600–1750 µS/cm. The proponent clearly intends to continue with this arrangement, despite the damage it would cause.

Apart from the fine issued by the Land and Environment Court of $200,000 for exceeding coal production limits, Coalpac's Invincible mine has been fined eleven times in the last ten years for incidents of non-compliance under the Protection of the Environment Operations Act, 1997 (see http://www.environment.nsw.gov.au/prpoeoapp/LicenceDetails.aspx).

RECOMMENDATIONS

The proposed Coalpac Consolidation Project (DA 10_1078) be refused development consent:

- As the proposed open-cut mining is inappropriately located, being too close to the village of Cullen Bullen and largely within a high conservation value public forest.

- As the extraction and burning of the inferior coal resources found within the project area will generate unacceptably high levels of carbon pollution.

- To avoid a precedent of establishing open-cut mining along the slopes of the Great Dividing Range and in other prominent escarpment locations such as in the Hartley, Capertee and Wolgan valleys.

- To prevent winding back the existing level of environmental protection embodied in the Invincible Colliery's development consent by replacing highwall underground mining with an approval for open cut mining over the same area.

- As open-cut mining of the environmentally sensitive slopes and gullies of the Great Dividing Range and the Ben Bullen Range cannot be adequately rehabilitated.

- As the highwall mining under cliff lines and pagodas would yield less than three per cent of the coal proposed to be produced from the project — the risks arising from such mining to operators and the environment are unjustified for such a low yield.

- To terminate discharges of eco-toxic groundwater from the old underground workings, arising from subsequent proposals to mine the coal pillars in the Invincible and Old Invincible collieries.

- To reinstate natural near-surface groundwater levels under swamps and to prevent further eco-toxic discharges into the EEC-quality Temperate Highland Peat Swamps on the Coxs River and Jews Creek, by allowing the abandoned underground workings to flood.

- To permit the removal of LDP 001 from Environmental Pollution Licence 1095, preventing further damaging effluent discharges from underground workings.

No licence for LDP 001 should be issued under part 5 of the *Water Act*.

The proposed sand mine should be refused consent due to: poor specification of the sand resource; known but understated risk of acid mine runoff and poor consideration of that risk; unwarranted interference and deferral of sequential rehabilitation of the proposed open-cut coal mine; assumed use of B-double trucks that cannot be used on the Great Western Highway; and insufficient description and environmental assessment of a relatively large quarrying proposal.

In refusing development consent the determining authority should find that:

- The proposed project area contains outstanding heritage values suitable for reservation under the *National Parks and Wildlife Act, 1974;*

- The presence of a remnant coal resource within mining tenements does not give the owner of those tenements any right to mine the resource because all mineral and energy resources are owned by the Crown;

- In order to help society avoid a climate catastrophe, the intensive open-cut mining proposed for the low quality coal resource within the proposal is best prevented through reservation of Ben Bullen State Forest as a state conservation area in order to set a positive precedent of sterilising such resources;

- The open-cut mining proposed is incompatible with either concurrent or subsequent reservation of the proposal area under the *National Parks and Wildlife Act, 1974* as heritage values are largely destroyed by such intensive mining;

- Areas of high conservation value, such as the Ben Bullen State Forest, should not be subjected to an environmental double jeopardy by being mined for a second time using more intensive mining methods that destroy heritage values in order to obtain the last remnants of coal in that area;

- The destruction of state forest by open-cut mining is inconsistent with the objects of the *Forestry Act, 1916.* Such mining could only be lawful if preceded by lawful revocation of the affected part of the state forest;

- It is beyond its gift to effectively overturn a reservation of a public state forest set aside by Parliament for permanent conservation and sustainable use by approval of an open-cut mine;

- Ben Bullen State Forest has for over 100 years already played more than its fair part in the energy economy of NSW, and it’s now appropriate to sterilise the remnants of coal resources in this state forest in order to protect the community and the environment from undue injury.

Thank you for the opportunity to make a submission on this open-cut coal and sand mining proposal.

The Colong Foundation for Wilderness does not make donations to political parties.

Yours sincerely,

K. Muir

Keith Muir
Director
The Colong Foundation for Wilderness Ltd

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[i] The prayer of the petition states
"Residents object to:
1 Increased threats to their health from fine and other damaging particles due to the proximity of the proposed open-cut mining activity.
2 Increased threats to the health of the children attending Cullen Bullen Public School from fine and other damaging particles due to the proximity of the proposed open-cut mining activity.
3. Increased threats to their property and public amenity from blasting and other high-impact, mining activity.
4. Increased threats to the quality of their lifestyle from any increase in the level of open-cut mining activity within hundreds of metres of their village.
5. Open-cut activity blighting the scenic landscape and impacting local tourism.
6. The loss of habitat for native plants and animals.
The undersigned petitioners therefore ask the Legislative Assembly to act to reject the open-cut proposal and take the necessary steps to protect the village of Cullen Bullen and the Ben Bullen State Forest from future open-cut mining proposals."
[ii] Castleden, WM, et. al. 2011 The mining and burning of coal: effects on health and the environment, Medial Journal of Australia.
[iii] Kim Hann, 2011, Blast Fumes
[iv] Central Council Natural Resources & Energy Policy Committee-The Nationals NSW, submission of 24 April, 2012 to the draft Strategic Land Use Policy, SECTION 4.0.

ATTACHMENT A

The Geoheritage and Geomorphology of the Sandstone Pagodas of the North-western Blue Mountains Region (NSW)

HAYDN G. WASHINGTON[1] AND ROBERT A.L. WRAY[2]

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[2]University of Wollongong, Wollongong NSW 2522 (email: (wray@uow.edu.au).

Washington, H.G. and Wray, R.A.L. (2011). The geoheritage and geomorphology of the sandstone pagodas of the north-western Blue Mountains region (NSW). *Proceedings of the Linnean Society of New South Wales* **132**, 131-143.

The towered 'pagoda' rock formations of the north-western Blue Mountains, west of Sydney, have a heartland of about 600 km^2, mostly at around 1000 metres altitude in Banks Wall and Burra Moko Head Sandstones. The pagodas are of two types: the 'platy pagodas' are generally stepped-cones in shape, with semi-regular ironstone bands, whereas the 'smooth pagodas' display less ironstone bands and are similar to many slickrock slopes found elsewhere. The platy pagodas however are an uncommon and significant geomorphic landscape feature, and are distinguished by the extent and regularity of their ironstone banding. The formation of the ironstone banding has involved the movement of iron in solution and its precipitation to form resistant bands, swirls and pipes. Questions remain as to how the ironstone banding formed, however 'roll fronts' of reaction between reduced Fe^{2+}-rich water and oxygenated water may best explain the amazing ironstone shapes. The geoheritage value of the pagodas is significant, but is threatened by activities such as longwall coal mining. The pagodas and the associated slot canyons of the Blue Mountains are ideal candidates for future geological and geomorphological research.

Manuscript received 1 November 2010, accepted for publication 16 March 2011.

KEYWORDS: Blue Mountains sandstones, geoheritage, geomorphology, ironstone banding, ironstone formations, Liesegang banding, pagodas.

INTRODUCTION

The 'pagodas' are a local name for distinctive sandstone formations in the north-western Blue Mountains region of NSW, west of Sydney (Fig. 1). These rocky cones are found in parts of three reserves of the Greater Blue Mountains World Heritage Area; the northern parts of the Blue Mountains NP, along the western edge of Wollemi NP, and in the Gardens of Stone NP. However much of the pagoda heartland is still found outside of reserves, principally on Newnes Plateau, Genowlan and Airly mesas in the Capertee Valley, and in Ben Bullen State Forest. The main concentration of the pagoda country covers around 600 km^2. Pagodas are conical rock formations formed by differential weathering and erosion of the local sandstones. They come in two forms. Smooth pagodas have relatively regular conical-shapes (without terraces), while platy pagodas are stepped and terraced cones that resemble Asian pagodas, ziggurats or step-pyramids. On platy pagodas, erosionally resistant ironstone bands from 1 to several cm thick project from the surface and form the hard surfaces of the terraces. These bands can project laterally from the underlying sandstone for tens of centimetres, and display detailed 3-dimensional forms that can resemble chairs and tables, pipes and pulpits. Pagoda complexes are part of wonderfully intricate, ruin-like, landforms that resemble lost cities and temples, and are also often associated with slot canyons and weathering caves. Their significance only started to be appreciated in the 1980s.

HERITAGE

Large sections of the pagoda region were incorporated into the Greater Blue Mountains World Heritage Area due to their biodiversity significance, particularly eucalypt diversity. However it is of concern that scenic, cultural and geoheritage values of the pagodas landscapes have not been fully appreciated or officially recognised.

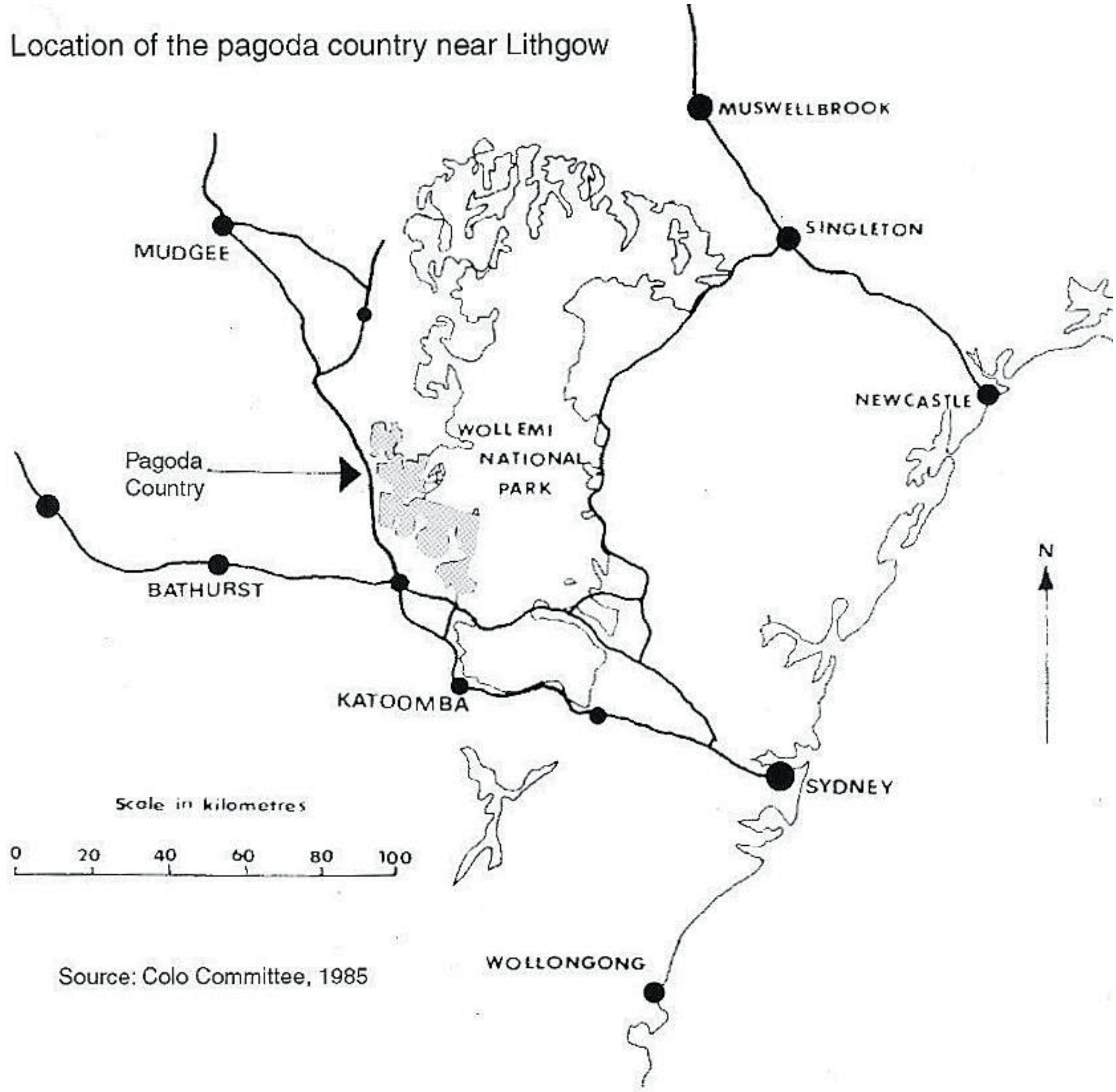


Figure 1. Map of the main distribution of the pagoda country in relation to Sydney, NSW (Washington, 2001a)

Geoheritage

The geoconservation significance of the pagodas has been recently recognised, but only to a partial extent. 'Geoheritage' as a term was originally only applied in Australia to *geological* features, not geomorphological or soil features (Sharples 1998). However, here we apply the broader usage of geoheritage (Washington 2001b), where the pagodas are geoheritage in view of the fact that they are uncommon and significant geomorphic sandstone landscape features.

The National Trust gave the first historical recognition of the visual and aesthetic significance of the pagodas when they proposed a Pinnacles National Park in 1977 (Washington 2001b). At that time these rock formations were called pinnacles, stuppas, beehives or just 'rocky outcrops', as on the 1:100,000 topographic maps. Although their visual beauty had been recognised by the National Trust, nobody had yet begun to appreciate their scientific values, such as geomorphology and botany. In the early 1980s a community non-government organisation the Colo Committee took up the campaign to conserve these rock formations, and along with the Colong Committee and the Federation of Bushwalking Clubs proposed the Gardens of Stone National Park (Colo Committee 1985). They focused on the term 'pagoda', which usage is now accepted for these smooth and stepped cones. At that time the pagodas locally were seen at best as interesting oddities, and at worst as sources of the 'black crinkly' bushrock that was sold on the Sydney market well into the 1980s.

Geodiversity – unlike biodiversity – is not alive, but it may be unique and significant and can be easily destroyed. The major impact on the pagodas has been subsidence due to longwall coal mining, where the ground surface can drop by up to 1.5 metres. While pagodas are quite geologically stable under normal conditions, the stresses of subsidence both crack pagodas and cause extensive cliff collapses. These collapses mostly occur along overhanging cliffs (often Aboriginal sites). This issue was highlighted at the Airly Commission of Inquiry in 1992, which investigated the proposal for coal mining of the Mt. Airly mesa in the then proposed Gardens of Stone National Park. At that time the Department of Mineral Resources (in response to a question by the Colo Committee) stated that in the Baal Bone Colliery area there had been 124 cliff collapses over 2-3 years, while in the adjacent Angus Place Colliery area there were 55 cliff collapses over the same period, some over 1,000 cubic metres (Washington 2001b). Significant cliff collapses have continued since (Muir 2010).

Mining subsidence can also impact on the Temperate Highland Peat Swamps on Sandstone (an endangered ecological community under the Commonwealth EPBC Act) through draining of aquifers and surface streams down strata shattered by subsidence. When the Colo Committee raised concerns in 1992 that the Department of Mineral Resources did not recognise the geomorphological value of these rock formations, the Department replied: 'That is not true, we do value the pergolas (sic)'. The confusion over the name, where 'pagodas' became 'pergolas', demonstrated that the geoheritage value of the pagodas was not being acknowledged at that time.

While Gardens of Stone National Park was proposed in 1985, a park by that name was not created till 1994, and covered only 11,780 Ha, later being extended to 15,080 Ha. The Park gazetted was the area of the pagoda country that did not overlie mineable coal (due to the thinning of the coal seams and 'bad roof' due to jointing). While some pagodas are found in the nearby Wollemi and Blue Mountains National Parks, and others are found in the Gardens of Stone NP, around half the core pagoda country is not protected in reserves. The main pagoda areas not protected are the Genowlan/Airly mesas, Newnes Plateau, and parts of Ben Bullen State Forest. Much of this area is covered by coal leases such as Airly, Baal Bone, Angus Place and Clarence.

The Gardens of Stone Stage 2 proposal of an additional 40,000 Ha was put forward in 2005 by the Colong Foundation for Wilderness, Blue Mountains Conservation Society and the Colo Committee. The proposal sought to form a State Conservation Area (SCA) over most of the area, which would have protected surface features but allows underground mining. Currently, the Department of Environment, Climate Change and Water (DECCW) has been working on a proposal to make the Genowlan and Airly mesas an SCA. This would allow 'bord and pillar' coal mining by Centennial Coal of the Airly Coal lease, but give protection to the surface features, including an extensive complex of pagodas, sometimes known as the 'Three Hundred Sisters'. The nearby Genowlan mountain is part of an area proposed for a future coal lease and contains an endangered ecological community (Genowlan Point Heathland) and a critically endangered plant *Pultenaea sp. Genowlan Point* (under EPBC Act), of which only 39 individuals were known in 2005 (Washington 2005), with only 26 being found in a recent visit in 2011.

The proposal to give SCA status to much of Newnes Plateau seems to have become bogged down due to a perceived conflict with forestry and popular 4WD and trail bike use. However, most of the pagodas on Newnes Plateau could be protected *without* conflict with these activities. There is an ongoing community campaign for the protection of Gardens of Stone II (Muir 2005).

Bioheritage

Given that biodiversity often is dependent on geodiversity, it is not surprising that the pagodas are a biodiversity hotspot for rare and threatened species. Pagoda areas offer many different habitats to species and also offer a refuge from fire and grazing to some plant species. Thus species survive there which may have gone extinct in the rest of the landscape. The rare Pagoda Daisy (*Leucochrysum graminifolium,* Figure 2a) is virtually restricted to pagodas. The rare *Prostanthera hindii* similarly is also mostly found on pagodas. In the northernmost part of the pagoda region, to the west of Nullo Mountain, a new species was found only a decade ago, now named *Leionema scopulinum*. It also is essentially limited to pagodas. Other rare or threatened plants often found on or near pagodas are *Pseudanthus divaricatissimus, Banksia penicillata, Acacia asparagoides, Epacris muelleri* and *Philotheca obovalis* (Washington 2001a). The 'regionally significant' *Eucalyptus oreades* is commonly found on and around pagodas. There are several threatened animals species found in and around pagodas. The Broad-headed Snake (*Hoplocephalus bungaroides*) is found on pagodas (as it lives under loose surface rock), while Glossy Black Cockatoos (*Calyptorhynchus lathami*) feed on *Allocasuarina* species found on and adjacent to pagodas. Raptors such as the endangered Peregrine Falcon (*Falco peregrinus*) use adjacent cliff habitats (e.g. Genowlan Point).

Cultural heritage

A number of Aboriginal art sites are found in sandstone weathering caves among pagodas, with Blackfellows Hand Aboriginal Place being the most famous. There are many other sites found in weathering caves in pagodas near swamps. There is also an extensive European coal and oil shale mining heritage associated with areas near pagodas, which dates from the 1880s (Colo Committee 1992). Oil derived from the kerogen in torbanite was used to replace sperm whale oil for domestic lighting. The western side of Wollemi NP contained narrow but rich bands of torbanite, and these were mined from Mt Airly, Newnes and Glen Davis. Mining heritage can be found at all these now-ruined sites, including steam winches, air shaft chimneys, and miners' cottages built into caves on Airly Mountain (Colo Committee 1992).

GEOMORPHOLOGY OF THE PAGODAS

These pagodas are an unusual landform type, and very little is known about how they form. What is clear is that pagodas are differential weathering formations found in the Banks Wall and Burra Moko Head Sandstones of the Triassic Narrabeen Group. The majority of platy pagodas appear to be found in the Banks Wall Sandstone, though smooth pagodas can be found in the underlying Burra Moko Head Sandstone. Both of these sandstones are fine to course-grained, porous sandstones, often with small pebble bands (Bembrick 1980). They were laid down in a massive river delta flowing from the north-west some 230 to 250 million years ago. Occasionally there are fine claystone bands intercalated amongst the sandstones.

Pagodas come in two forms – 'smooth' and 'platy'. Smooth pagodas (Figure 2 b and c) resemble cones or beehive structures found in the Bungle Bungles, Budawangs and other areas around Australia and the world (Young, Wray and Young 2009), such as the central-west USA where they would be called 'slickrock' slopes (Howard and Kochel 1988). Platy pagodas (Figures 2 d, e, f) however commonly have regular ironstone banding every 20 cm to a metre that can extend up to 60 metres in height. This banding is generally 2-5 cm in thickness and can, because of erosion of the surrounding friable sandstone, often project 20-40 cm from the sandstone (and in exceptional cases can project up to a metre). This ironstone plays a major protective role, and smooth pagodas appear to be eroding far more quickly than platy pagodas (we estimate at least 10 times faster, though this needs further research).

Platy pagodas are in our view distinct and significant features, as we are not aware of any other rock formations in Australia or overseas that mimic the geomorphology of platy pagodas (see Young, Wray and Young 2009). While there are many other rock pinnacles and beehives around the world, and while ironstone formations are found in other places, the regular stepped-cone shape of platy pagodas is a distinct geomorphic feature. The ironstone banding of the platy pagodas is thus significant in degree, not in nature, as ironstone is found throughout the Sydney Basin. However, the development of banding in platy pagodas forms a distinct geomorphic landscape unit. By analogy, limestone caves are significant, even though limestone is common. The reason why platy pagodas are virtually restricted to this area may be due to the friable nature of the porous bedrock itself, the amount of iron present in the sandstone, or aspects of former climate and associated hydrology. The exact formative mechanisms of platy pagodas remain unclear, but several hypothesis and suggestions for further research will be presented.

The erosional formation of the smooth beehive-shaped pagodas and similar 'slickrock slopes' elsewhere is fairly well understood (Howard and Kochel 1988; Young, Wray and Young 2009). Similarly, platy pagodas appear to result from the differential weathering of the resistant ironstone banding and the much softer, friable, surrounding sandstone. However, it is not known how the regular ironstone banding of platy pagodas has formed, and it is noteworthy that until now nobody seems to have asked these questions or published on this issue.

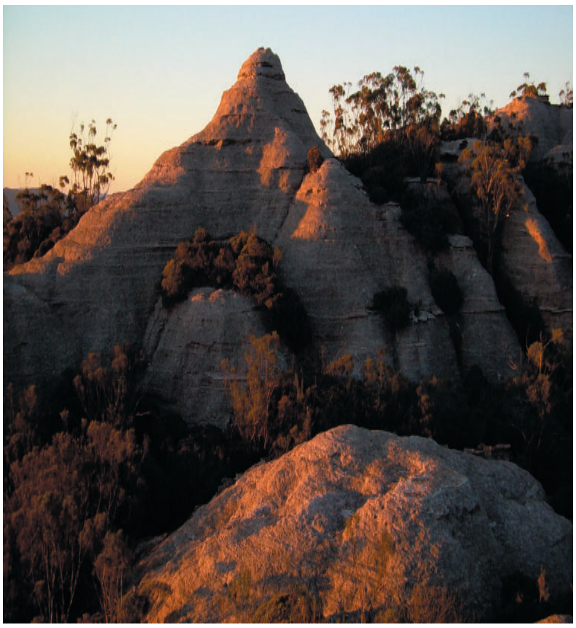
It has been suggested in community discussion over the years that the ironstone was possibly formed during deposition of the sediments. Given that these sediments were laid down in the delta of a large river,

Figure 2 OPPOSITE, a: Pagoda Daisy (*Leuco-chrysum graminifolium*); b: Smooth pagoda at Pt. Cameron, with platy pagodas in strata below; c: detail of b; d, e: Platy pagodas, Bungleboori Ck, Newnes Plateau; f: Platy pagodas at Gooches Crater.

a

b

c



d

e

f

it is difficult to see how precipitated iron could have been deposited, which later reformed as ironstone in the 3-dimensional shapes seen within these sandstones. Whilst there is clear evidence that ironstone sheets commonly follow vertical cracks or joints in the sandstone (Figure 3a), the sub-horizontal ironstone layers are clearly not bedding-related features, as the 3-dimensional ironstone layers clearly cut across beds, and there are also ironstone piping (Figure 3b) and multi-dimensional ironstone sculptures (Figure 3c).

The iron thus appears to have reached its location through solutional processes, possibly when reduced Fe^{2+}-rich water precipitated out as ironstone. This was also the conclusion of Beitler et al. (2005) regarding the iron movement and ironstone formation within the Navajo Sandstone in the central US. Another suggestion for smooth pagoda formation has been that they are buried landscapes (e.g. dunes). This is not supported by the evidence, as while smooth pagodas may resemble dunes, they are rapidly eroding erosional landscapes that keep their shape not because they were buried dunes but because they are erosional features. The pagoda formation raises many questions, which are addressed in the following sections.

The Source of the Iron

The source of the iron remains a matter of debate. Some geologists suggest it is derived from former overlying basalt (as argued by Dr David Roots of Macquarie University in the 1980s). Remnant Tertiary basalt caps are found on Airly Turret and Mt Cameron in the north of the region, and on Mounts Wilson, Banks, Bell, Irvine, Tomah, Hay, and Tootie in the south, and these show that some small and localised basalt flows did occur near the pagoda region. Weathering of former overlying Tertiary basalt flows may have contributed locally to the iron content of the underlying sandstone. However, there is no definitive proof that basalt once covered the whole (or even significant parts) of this area, as noted by Dr John Pickett of the Geological Survey of NSW.

Others believe it originated from leaching of the iron coatings on sand grains and the iron cement in the sandstone itself (again noted by Dr Pickett). Leaching of 30% of the iron in coatings has been known from bleached zones in the Navajo Sandstones in Utah (Chan et al. 2006), which has then precipitated into ironstone formations that can contain 35% iron (Beitler et al. 2005). We agree with the second interpretation, that the iron comes predominantly from within the sandstone itself (possibly deep weathering during the Tertiary), but this needs further research.

Figure 3: a ABOVE, iron-indurated vertical crack; b OPPOSITE, ironstone tubing; c: ironstone sculpture on Wolgan/Capertee divide; d: Massive ironstone deposition above impermeable Wentworth Falls claystone (e) at Bungleboori Ck; f: 'dragon skin' ironstone nodule sheet (nodules c. 1 cm).

b

c

d

e

f

Hydrothermal hypotheses

Did the iron-rich water come from hydrothermal vents from basalt dyke intrusions, such as Varilova (2007) postulated for similar looking ironstone layers within sandstones of the Bohemian Switzerland National Park? While in that area there are nearby basalt dyke intrusions, no such intrusions have been found near the pagoda region. In any case, there is no evidence of how hydrothermal vents might have formed from such possible overlying basalt flows. Given the amount of ironstone present (which in places is rich enough to be an iron ore), evidence of hydrothermal vents should be more obvious.

Timeline of iron precipitation

It would be useful to know *when* the iron precipitated in the sandstone. Was this a single geological event, or were there a sequence of such events? Examination of oxygen isotope fractionation within authigenic clays in the ironstones may clarify this question. Palaeomagnetism of the ironstones may also reveal information as to the timing of ironstone formation. Determining the time of the formation of the ironstone banding may suggest how it was formed (e.g. whether it was associated with events such as volcanic activity in the Tertiary that may have shattered impermeable layers and allowed reduced iron-rich water to mix with oxidised surface water?).

Geochemistry of iron precipitation

It has been noted that oxygenated Fe^{2+} originally precipitates as polynuclear aggregates of Fe^{3+} hydroxides and ferrihydrite (Cornell and Schwertmann 1996), which are converted to a polymorph of FeO(OH) such as goethite, and finally to hematite (Berner 1980). Certainly a transition does occur with ironstone banding within sandstone bedrock on Newnes Plateau, as when uncovered (in sand quarries and road cuttings) the banding is light red and fairly soft. This then changes over a few months to become a deep purple colour and is much harder. Beitler et al. (2005) note that for Navajo Sandstone the presence of both iron oxide phases indicates multiple precipitation events with different geochemical conditions or progressive dehydration of goethite to form hematite. This may explain the change in colour and hardness of ironstone banding newly exposed to the Australian weather. Much more detailed geochemical investigation, including examination of iron-isotopes, may elucidate these aspects.

Three-dimensional ironstone banding

Platy pagodas contain extensive three-dimensional whorls, curves and pipes. While the ironstone formations in places follow cracks and other discontinuities in the sandstone where water might percolate, in the larger majority of instances it passes right *across* bedding planes. What can be responsible for this, to the extent that it can form piping, curves, and complex 3-dimensional sculptures formed by the coalescence of several ironstone bands? We believe the most likely explanation may be due to ‘roll fronts’ between reduced iron-rich water and oxygenated surface water. This has been postulated by Beitler et al. (2005) for the Navajo Sandstone (Fig. 4). Some concentric banding patterns have been called ‘ironstone roses’ and have been ascribed to Liesegang rings (Varilova 2007). We believe that the complex three-dimensional structures may reflect both vertical and horizontal movement of iron through the sandstones, leading to a complexity of formations not seen in the simple Liesegang banding in gel experiments in the laboratory.

Chan et al. (2006) note that precipitation of terrestrial concretions is thought to occur when Fe^{2+}-bearing (reduced) fluids intersect oxidizing groundwaters, where oxidation of iron at near-neutral pH would produce immediate precipitation of iron oxide at the mixing interface (Von Gunten and Schneider, 1991). Precipitation of iron oxide would be concentrated within a spatially-limited reaction front corresponding to this mixing interface. Beitler et al. (2005:556) note that ‘This combination of advective and diffusive processes could account for the complex mineralization patterns seen in the field’. Interestingly they also note that ‘Spatial relationships between bleached zones and iron-rich facies indicate that in some areas iron ions have traveled several kilometers before oxidation’. Concretions that precipitate within such a reaction front are commonly spheroidal in shape (Chan et al. 2006), and this might also assist in explaining the undulating nature of many ironstone bands, and possibly how tubular structures form? We recognise that while ‘roll fronts’ might explain how the amazing diversity of ironstone shapes could come about, it does not fully explain the process that leads to these formations, especially the regular banding of platy pagodas.

Regular ironstone banding

Apart from the 3-dimensional ironstone structures found in pagodas, there is also the regular sub-horizontal banding at a spacing of 0.2 to 2 metres, which can occur over heights of up to 60 metres. What best explains this? Is the regularity of the layering due to sequential events over geological time? Regular banding was *not* found in the Navajo sandstone, where Beitler et al. (2005:559) noted:

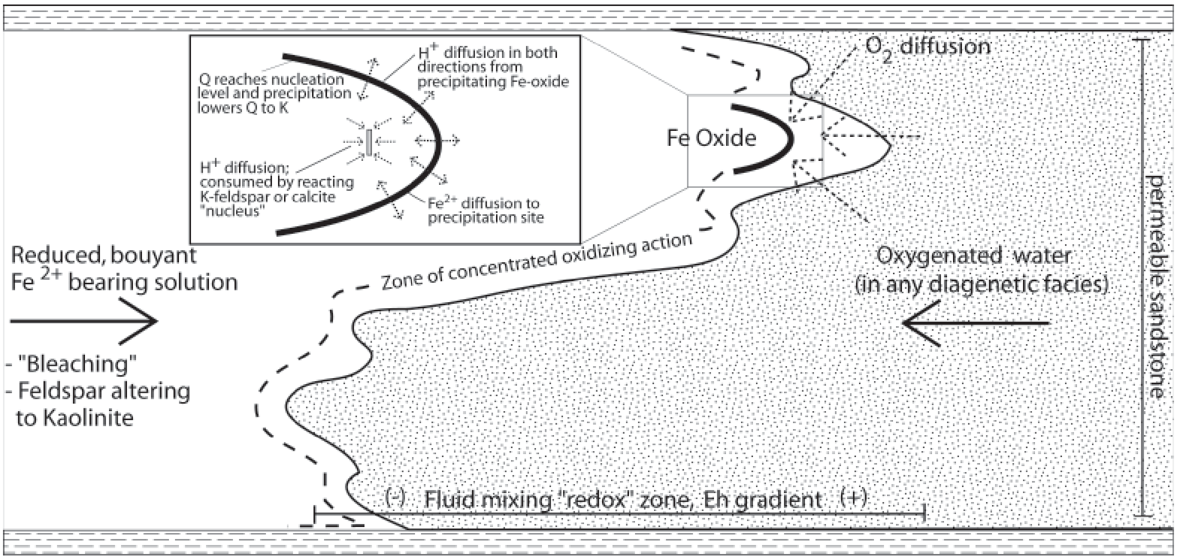


Figure 4 Generalized conceptual model of an oxidation-reduction front with precipitation of ferric oxide near the interface between oxidizing, O2-bearing water and reduced, Fe2+-bearing waters. A reduced, Fe2+-bearing solution moves to the right into a region of porous rock containing oxygenated water. (From Beitler et al. 2005, Fig. 12)

> 'The iron staining is commonly diffuse and permeates the sandstone on one side of the joint, and terminates abruptly on the other side of the joint, indicating directional fluid mixing and diffusion. The joints were likely conduits for oxidizing meteoric groundwater that infiltrated the sandstone and created a local oxidizing environment. If the sandstone was saturated with reducing iron-saturated fluid at the time of joint formation, the influx of this meteoric water would have resulted in precipitation of iron along this increased permeability zone.'

They thus found that joints were an important means of flow for oxidising water, but the ironstone was diffuse and not banded. What then causes the regular banding found in the sandstone of the platy pagodas? One hypothesis we have considered is that they are due to a series of wetting and drying events. It may represent a regular sequence where water moved through the sandstone as an aquifer, and ponded to a certain depth (e.g. on top of a claystone layer), then Fe^{2+} was precipitated out on the top of this water surface (due to higher oxygen levels, possibly due to arrival of oxygenated surface water) to form a new impermeable layer. More water then ponded to a similar depth on the new impermeable layer, which then precipitated Fe^{2+} to lay down another impermeable layer, and so on. This would suggest that under those conditions there was an optimum depth of water pooling in the sediments where the Eh and pH conditions were suitable for Fe^{2+} to precipitate out as Fe^{3+} in iron hydroxides in a horizontal 'roll front', which later formed into goethite (and then upon exposure, hematite). The banding may thus be a function of the properties of the porous sandstone itself, plus the climate and hydrology at the time, and the iron geochemistry associated with this.

As the distance between the bands varies from place to place (from 0.2 metres to 2 metres), this may reflect differences in the sandstone porosity, iron content, local hydrology and geochemical conditions. Field observations lend some support for this hypothesis, in that the most massively iron-indurated sandstone (Figure 3d) is often the layer immediately above a claystone band (Figure 3e). In places it seems these impermeable layers may only need to be quite thin to cause major iron induration. This may mean that the first leaching cycle extracted the greatest amount of iron, which was then indurated in that first layer. The presence of massive amounts of deeply weathered (> 60 metres) sandstone on Newnes Plateau (Peckover 1986) shows this region was subjected to major episodes of leaching and weathering. The question remains as to when this took place, given this area has been exposed to weathering since at least the early to mid-Tertiary (Young, Wray and Young 2009). Pickett and Alder (1997) also believe this leaching probably took place during the Tertiary.

Another explanation that may explain the regular banding is 'periodic precipitation', similar to the phenomenon known as Liesegang banding. This explanation for platy pagodas was suggested by geophysicist Prof. Marjorie Chan of Utah University. Hantz (2006) notes regarding Liesegang banding:

> Although the Liesegang phenomenon has been studied for over a century since its discovery in 1896, the mechanisms responsible for these structures are still under discussion. The models that try to explain the pattern formation can be divided into three main classes: supersaturation, sol coagulation and phase separation theories.
>
> All of these theories can reproduce the most important macroscopic characteristics of the bandings, but none of them is able to explain all the experimental findings. It is reasonable to assume that several mechanisms account for the Liesegang banding.

The complexity of the iron banding (with occasional gaps between banded areas) poses the question as to whether there may have been more than one precipitation event. This has been postulated in regard to small 'Liesegang blocks' in Iran (Shahabpour 1998). For this to occur in the platy pagoda banding however would mean that the bands formed are not immediately impermeable, and allow the reactant (e.g. oxygenated water moving down or reduced Fe^{2+} water moving upwards) to continue to pass through the rock. However, ironstone banding is often now observed to be impermeable, but this impermeability might possibly form later as the iron hydroxides later change to goethite and/or hematite. Horizontal flow of reduced iron-rich water between existing ironstone bands may possibly form other ironstone bands. This may explain the most heavily indurated ironstone areas above aquacludes. The regular ironstone banding of the pagodas remains one of the most difficult aspects of pagoda morphology to explain. Our above discussion details two hypotheses to be considered by future research.

Distribution Patterns and Controls

What determines where platy pagodas form? This may be due to three processes. Firstly, the faster erosion occurring along existing joints and valleys would allow platy pagodas to erode out in these areas. Secondly, the sites where one finds pagodas may be due to the fact that ironstone banding is not distributed uniformly across the strata that give rise to platy pagodas, so that the banding is *thicker* or more prevalent in some places. Certainly from field observation the thickness of bands varies from place to place. Ironstone banding can be seen in some of the friable sandstone quarries and road cuttings on Newnes Plateau, though this can be quite thin in places compared to that seen in pagodas. Thirdly, much of the pagoda country is deeply weathered (which presumably originally mobilised the iron). Newnes Plateau contains half a billion tonnes of friable sandstone (Peckover 1986). The degree of weathering may vary from place to place, so that in some areas the bedrock retains more cement between the grains. The formation of platy pagodas may thus be a function of enough protective ironstone banding, in addition to whether the bedrock between the bands is weathered to a greater or lesser extent. Even with banding present, if the bedrock is so weathered as to erode quickly, the pagoda may collapse and the banding be fragmented into ironstone debris. Such ironstone debris is commonly seen in places on Newnes Plateau, and near other pagodas. At this stage, we do not know which process is dominant in the formation of the platy pagodas we see today. Quite likely all three aspects are operating. Examination of drill cores and the friable sandstone quarries may provide further evidence as to the uniformity of banding, its thickness, the weathering of the sandstone, and whether such sites could form pagodas in the future upon differential weathering.

Impermeable bands

To what extent do claystone and ironstone bands determine water flow and hence where iron precipitates out? Claystone bands of various thicknesses are common within these sandstones, and begs the question whether these function as impermeable layers that have directed groundwater flow and ironstone formation? Claystone and ironstone bands function in the central Blue Mountains as impermeable layers that direct water along strata that feed hanging swamps (Pickett and Alder 1997), and they should function similarly in the north-western Blue Mountains. However, sometimes claystone bands in overhangs in the pagoda region can be seen to have been breached by cracks, and the iron-rich water has passed through to the strata underneath (and formed banding). In other places the impermeable claystone is intact and the ironstone banding is much thicker and more massive on top of these claystone bands (which in some spots may only need to be quite thin). This may account for the massive ironstone 'sculptures' which can be several metres high (Figure 3c) that are found in many places. The action of impermeable claystone bands may also explain why a strata under such a claystone band has extensive ironstone banding and platy pagodas, while the strata above the band is virtually free of ironstone and has only smooth pagodas (as observed at Point Cameron on the Wolgan/Capertee divide). In that location it would seem iron-rich water only had access to the lower strata, but not the upper. Similarly, massive iron-banding can be found in platy pagodas on top of the Wentworth Falls Claystone, while the Burra Moko Head Sandstone underneath contains mostly smooth pagodas (seen in the 'Lost World' on Bungleboori Ck). Claystone bands would thus seem to function as water barriers, where a strata that carries iron-rich water (due to water flow controlled by impermeable layers) forms iron banding, while another does not, as iron-rich water cannot reach it. This needs further research.

Bacterial influence

The role of bacteria in iron dissolution and precipitation needs to be clarified. as it is noted in the literature that bacteria are involved in both the reduction and oxygenation of iron in sandstone. Beitler et al. (2005:559) note in regard to the Navajo Sandstone that 'Bacteria commonly mediate iron mobilization and precipitation and could possibly be an important component of this system (Cornell and Schwertmann 1996)'. However, the complexity involved in the bacterial control of iron precipitation does not seem to have been adequately explained in the literature. Are the amazing ironstone shapes found in pagodas in part due to bacterial colonies in the sandstone changing Eh and pH and thus precipitating Fe^{2+}? Certainly cracks and weaknesses in the sandstone would allow greater water flow and hence may bring more food to bacterial colonies at these sites, hence Fe^{2+} may precipitate to a greater degree along with the higher bacterial density.

There is also the question of whether bacteria are present in nodular ironstone concretions found on ironstone sheets in pagodas, known colloquially as 'dragon skin' (Figure 3f). Nodular iron structures have been noted elsewhere in ironstone formations (Chan et al. 2006; Varilova 2007). However, no detailed study seems to have been carried out to date on the bacterial involvement with iron precipitation in ironstone. Chan et al. (2006) note that ironstone nodules also form on Mars, where bacteria may not be involved, and suggest that nodular sheets may just be a function of reaction fronts in active chemical systems. This is clearly an area in need of further investigation, where the possible application of iron-isotope studies may shed light on the action of bacterially-mediated iron precipitation.

Present day activity

Does ironstone precipitation continue today that will one day weather out to form pagodas? Iron is still being dissolved and is moving in solution across the landscape and precipitating out in swamps such as Long Swamp Creek (headwaters of the Cox's River). In such swamps it might then be reduced in the sediments and then move downwards and sideways through the porous sandstone, within the controls exerted by the impermeable claystone bands. In this regard iron induration of sandstone may still be continuing today, laying further ironstone layers that may form the pagodas of the future. Alternatively, was all the ironstone banding laid down in one key geological event? If it proves possible to date ironstone banding, it may answer this question. If ironstone banding is still forming, then it raises the question of how swamps may have been involved in the past iron induration of the sandstone. A casual examination of pagodas clusters shows a linearity evidenced in many places, but this may just be due to linear jointing and erosion along these joints. However, swamps also form along such joints (e.g. the shrub swamps of Newnes Plateau) where iron could seep into sandstone over many thousands of years. As such, the formation of ironstone banding may still be ongoing. This issue remains a fascinating hypothesis for future research.

CONCLUSION

The pagodas are a case-history of how difficult it can be for something to be recognised as geoheritage. It is also an excellent example of why the concept of geoheritage in NSW needs to be expanded beyond just geological sites to include geomorphological and soil sites. If geodiversity and geoconservation in the literature are seen as applying to all three categories (geology, geomorphology and soils), then so also should geoheritage. The north-western Blue Mountains pagodas were originally appreciated for their scenic grandeur, and only later started to be recognised and understood as 'hotspots' of biodiversity. However, science was slow to appreciate just how distinct and significant pagodas (especially platy pagodas) are as a distinct landform. Iron movement and precipitation within these sandstones seem to have been taken for granted as a process, and scientists have been slow to ask just how pagodas, particularly platy pagodas, actually formed. We conclude that they are distinct and significant geomorphological features, even by world standards.

Despite these significant values, the geoheritage of the pagodas is still under threat, largely due to underground longwall coal mining, but also due to damage by human trampling. There have however been advances over the years as recognition of their geoheritage value has increased. For example, the orientation of some coal mining longwalls have been changed, or terminated earlier, to protect particular pagoda formations (e.g. Oakbridge Colliery stopped a longwall short of the 'Artefact' pagodas in Baal Bone Colliery, Washington 2001b). Protection zones have also been created in coalmine operation plans to protect some areas containing pagodas and swamps. The use of 'bord and pillar' coalmining can reduce subsidence if the pillars are retained (as Centennial Coal has agreed to do in some areas), and hence can protect overlying pagodas. One coal company, Centennial Coal, has been willing to consider the idea of a State Conservation Area being created over their coalmining lease at Mt. Airly.

However, just as Australia has been slow to acknowledge its wealth of biodiversity, the pagodas show that we have been similarly slow to recognise the significance of our geodiversity, and the platy pagodas are certainly a distinct and significant part of Australia's geodiversity. The formation of platy pagodas has yet to be full explained, but their geomorphic significance is not in doubt. We believe that pagodas and their associated sandstone landforms (such as slot canyons) are important and significant parts of the sandstone geodiversity of the Greater Blue Mountains World Heritage Area and adjacent unprotected areas. This is of significance given the Commonwealth Government plans to renominate this World Heritage Area for geodiversity in the future (currently it is listed only for biodiversity). Pagodas deserve full and expanded recognition as a significant part of the geodiversity and geoheritage of the Blue Mountains region. Their natural aesthetic beauty, their biodiversity, and their significant geomorphological values mean they deserve enhanced recognition and conservation into the future.

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