Glasshouse Mountains National Park (Coonowrin)

Risk Analysis considering
Random/Natural Rockfall Incidence

Foreword

This report is provided as a courtesy to, and for the benefit of, the people of Queensland and their appointed land managers of the area, presently Queensland Parks and Wildlife, and the greater government departments that have managed QPWS during the study: EPA and DERM.

I, the author, have had a long relationship with murri people in my own area and wish all the best outcomes possible for the first peoples across Australia. I wish to acknowledge the first people of the area related to this report, and their unique relationship with the land.

This report does not seek to address any issue other than the one stated in the section *Purpose* on page 19. As a result this report makes no comment on indigenous or wilderness management theory issues of any kind, although the author would welcome the chance to contribute to this topic at another time.

The author undertook to perform this study as a personal initiative for the public benefit. As a voluntary work, this report does not provide an academic or professional guarantee as to the certainty or applicability of the findings, however the undertaking of the author was to be meticulously diligent and factual in both undertaking the study and in compiling this report to a professional standard.

While the author, a registered professional engineer, has drawn expert knowledge from a team of professional geologists, engineers and risk managers, the provided observations have been deliberately limited to those that any member of the public with knowledge of the relevant maths could provide, with the exception of a few geological comments that were provided by a geologist as noted at specific locations in the report.

Since this work is the result of a personal initiative the study did not have a brief from QPWS, and as such the author was free to examine any matter that was considered to be most important in understanding the topic of risk of random rock fall at Coonowrin. Similarly, as this report is a voluntary work, it is not formatted to comply with any specific formal document standard. However I have made every effort to make the report accessible so that the most important information can be easily found, while still containing the necessary level of foundational evidence.

I have made every effort to make this study correct and valuable, and welcome professional critique of the content anticipating that such critique can only serve to improve the information available to the area land manager so as to improve their capacity to manage the area in the best interests of the people of Queensland.

Acknowledgements

I would like to thank the following people for their assistance and advice.

I would like to thank, but have withheld the names of, a number of practicing Professional Civil Engineers and Geologists who reviewed my work for material error.

I would like to thank, but have withheld the names of, two practicing lawyers who advised me on matters of aboriginal title law and on some matters of government practice in general.

A number of people also provided proof reading of drafts of this report, and I would like to thank them but have withheld their names as the author wishes to confine attribution of this work in case of any adverse response to errors and oversights.

Thank you to Mark Gamble, who provided the long distance photographs in 2007 and 2008, used in the comparisons. Thank you to Mike Meadows who provided the 1929 photographs from his archive. Images are credited where sourced outside the research team; uncredited images are from photographs or video footage taken by the team.

Thank you to the following volunteers who accompanied me on research trips to provide the necessary level of personal safety to satisfy the conditions of the QPWS permit (in order of trip dates): Mark Gamble, Ron Farmer (FMR), Phil Box (FMR), Ivan Aird, Frank Bowling, Barbara Makepeace, Andrew Barnard, Chris Barnard, Roger Whitton (SES), Darren McNamara (SES), Astrid (surname unknown, SES), Dave Reeve, Ruth Reeve.

Thanks to the local SES in general and to the leader during the study era, Graham Cheale, with whom I checked in and checked out of the area by phone on the days of site visits.

Thanks to the local QPWS staff and rangers, who spoke with me by phone on numerous occasions, met me in person to review my study and report progress and provided the access permit to perform the site observations.

Thanks to staff of the local quarrying company, Hanson, who met with me and reviewed my interim findings with a view to ascertaining whether the study had any information that could assist them in their safe operation of the Beerwah quarry site.

Finally, thanks and apologies to my family and others whom I have deprived of many hours of my time in undertaking this work.

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1 Executive Summary

1. This report's scope is limited to the topic **"What is the most significant information concerning the incidence of spontaneous rockfall at Coonowrin that can now be reported and that better informs the appointed land managers as to the safety of visitors to that location."**
2. The following frequencies and modes of rockfall were derived primarily from Coffey (Coonowrin) 1999 [1], so that this risk analysis is relying on the most authoritative source of information regarding rockfall incidence.
    a. Fall of 3 to 4 blocks each of volume 0.5 m^3 per year along the South and East faces.
    b. Fall of 1 block each of volume 0.5 m^3 per year along the North and West faces. This is an extension of Coffey (Coonowrin) 1999 [1], as this aspect was not treated.
    c. Minor landslide of a bulk of earth and/or rock on the North and West faces – volumes ranging from $1m^3$ to 1,500 m^3, using a frequency of "1 fall per 30 years".
    d. Major landslide of a bulk of earth and/or rock on the North and West faces – volumes ranging from $1m^3$ to 40,000 m^3 using a frequency of "one per 3160 years".
3. The calculations of theoretical risk levels based on Coffey (Coonowrin) 1999 [1] predictions of rock fall rates gave the following results:
    a. The annualised personal risk of fatality due to random rock fall confronted by the variety of visitor types historically typical at Coonowrin is in the range of 0.4 per million and 4.3 per million.
    b. It was rumoured that some local residents practised a regular constitutional walk around the area. If so, that visitor type would attract a higher risk due to the greater exposure, calculated to be approximately 40 per million.
    c. These risk levels fall within the safe recommended levels of risk under common risk analysis categorisations, including AGS (2007) [6] guidelines, specifically:
        i. The risk taken by **local residents** falls within the **"tolerable range" for "existing slopes"**.
        ii. All the **other modes** of access fall within the **"acceptable" range for "existing slopes"**.
    d. It was calculated that there is an accumulated 1.35% probability that a fatality would occur due to random rock fall during a single departmental administrative span of 20 years duration, given a resumption of uncontrolled access at 1990's levels of attendance.
4. Analysis of comparative long distance photographs available from various times in history of the four compass angles of the mountain identified the following:
    a. The faces are largely unchanged over an 80 year period from 1929 to 2008, a ten year period from 1999 to 2008, and a one year period from 2007 to 2008.

   b. Instances of optical mismatches that were found in close examinations approximate to an amount within the expectations of the theoretical rockfall quantifications.
   c. Of particular significance is the identification of optical matches with 1929 photographs in the details of the rock surface in areas marked in Coffey (Coonowrin) 1999 [1] as “recent rock fall”. This validates a theory that those surfaces have not suffered significant rock fall in the last 80 years at a minimum and therefore the recency of the rock fall must be interpreted as being a geological recency (hundreds to thousands of years, if not very much more like 10,000-1,000,000 years) rather than recency in a human time scale (years to decades).
   d. Of particular significance is the identification of matches in the details of the rock surface in 2008, ten years after Coffey (Coonowrin) 1999 [1], in areas marked in Coffey (Coonowrin) 1999 [1] as “very high risk”. This validates a theory that those surfaces have not suffered significant rock fall in the ten years since Coffey (Coonowrin) 1999 [1].
   e. Of particular significance is that there are relatively few probably verifiable falls in a detailed one-year comparison test arising in areas marked in Coffey (Coonowrin) 1999 [1] as “very high risk”. This validates a theory that those surfaces are not currently suffering from an accelerated rock fall rate.
   f. Based on the above, indications in Coffey (Coonowrin) 1999 [1] that areas of the rock surface are “very high risk” does not extend to forming expectations that there will be a high frequency of rock fall from those faces during a typical one year either timeframe.
   g. Also of note is the fact that there are very few identified fall candidate sites directly impacting the common walking track route of the 1990s, indicating that the theoretical risk analysis provided in this report, which assumes a uniform distribution of rock fall, is conservative in this aspect. It appears that less falls may occur over the original walking track than over other areas of the peak’s base that were historically less frequently accessed.
   h. Photographic comparison results propose a fall rate of around 10 incidents of significant rock fall during the year 2007-2008 on the South and West faces, averaging $0.3m^3$ each, totalling a volume of around $3m^3$.
   i. This correlates well to the theoretical fall rate predicted by Coffey (Coonowrin) 1999 [1] of an average rockfall around the peak of 3 to 4 falls per year each of $0.5m^3$, totalling $1.5m^3$ per year, validating the use of the Coffey (Coonowrin) 1999 [1] fall rate/volumes in the theoretical risk calculations in this report.
   j. The relatively small difference between the observed and theoretical fall rates is expected to be due to the limitations in the method of identifying each single rock’s status from the long distance photographs.
5. Walk-arounds of the site were performed to look for fresh fall sites on the ground.
   a. Over the two year study, there were four specific incidences found of a single rock fallen to the ground, all below the East face. The sizes

were estimated as $0.24m^3$, $0.11m^3$, $0.08m^3$, and $0.024m^3$. On average they had fallen from low on the East face and rolled around 10m. This observation supports the frequency of rock fall proposed in the theoretical expectations of Coffey (Coonowrin) 1999 [1].

   b. There is a single location under the North face where small shards of rock have fallen to the ground at an undetermined but obviously accelerated rate compared to the rest of the site, and in a continuous, predictable, slow pattern. This location presents the highest probable frequency of rock fall on site, but is well out of the way of the common human traffic path of the 1990s.

6. Various important elevated features were examined at first hand as follows:
   a. The perched block identified in Coffey (Coonowrin) 1999 [1] was agreed to be perched on a slip plane, but was discovered by close examination and in conference with a consulting geologist to be bonded into the mountain higher up. Only when this bond releases will the block be free to move off its perch and down to the ground. While this event will be dramatic, it is also highly unlikely to be in our lifetime and presents only a very low probability of risk to daily visitors.
   b. A large rock movement was detected by the author as having occurred in the 1990s within the upper North face cave. Movement in this cave seems to be highly active in a geological timeframe and presents an excellent opportunity for the study of geo-mechanics. It presents a low probability of risk to human traffic, as it is extremely inaccessible.
   c. Brown rock identified at a distance in Coffey (Coonowrin) 1999 [1] as "recent rock fall" was examined at first hand to be a strongly bonded crust of rusty mineralisation at least centuries and more likely to be millennia old. This indicates the recency of any rockfall as being in geological time, and beyond exceptional consideration so far as being a risk to human traffic.
7. **In summary, from both theoretical extensions to Coffey (Coonowrin) 1999 [1] estimations of rock fall frequencies and intensive observations on site, the risk to any individual visiting the site falls within common guidelines for personal risk acceptability.**
8. The rock feature described in this report as "Coffey's block" and the Mank Master cave are potentially vulnerable to more rapid change than the rest of the location. It is possible that Coffey's block could be prematurely dislodged by a major earth tremor, and any such event occurring artificially should be absolutely avoided in the interests of preserving this iconic natural feature.
9. **There was little found in this study to validate continued restricted access.**
10. **It falls in the domain of the land manager in consultation with the public to ascertain an appropriate form of presentation.**
11. The following two forms of presentation are noted for consideration, as they are the most prominent options on offer in current practice.
    a. **It is possible to envisage that personal access permits can be issued to anyone who applies for such at present without additional constraints being necessary, beyond risk advice and acceptance.**

b. **There is no clear reason not to simply remove the current access restriction and permit general access, returning the location to being managed by the common regimes in use in the area.**

2 Document Citations

These texts are cited in this report.

Abbreviation	Document
Coffey (Coonowrin) 1999 [1]	Stability Assessment, Mount Coonowrin, 12 April 1999 – Coffey Geosciences Pty Ltd, for Qld Dept of Environment and Heritage
Coffey (Beerwah) 1999 [2]	Stability Assessment, Overhang Area, Mount Beerwah, 12 April 1999 – Coffey Geosciences Pty Ltd, for Qld Dept of Environment and Heritage
Coffey (Beerwah) 2006 [3]	Slope Stability Risk Assessment for Mount Beerwah Track, 15 August 2006 – Coffey Geosciences Pty Ltd, for Qld Parks and Wildlife Service
ANZECC [4]	Visitor Risk Management and Public Liability, 1998 - Australian and New Zealand Environment Conservation Council http://www.environment.gov.au/parks/publications/best-practice/pubs/risk-management.doc
AGS 2000 [5]	Landslide Risk Management Concepts and Guidelines, 2000 – Australian Geomechanics Society http://www.australiangeomechanics.org/resources/downloads/#dlLRM2000
AGS 2007 [6]	Landslide Risk Management, 2007 – Australian Geomechanics Society http://www.australiangeomechanics.org/resources/downloads/#dlLRM2007
Qld Gov [7]	Queensland Government Risk Management Resource http://www.deir.qld.gov.au/workplace/subjects/riskman/fivesteps/index.htm
Smithies [8]	Guide to Climbing in the Glasshouse Mountains - Col Smithies

3 Further Reading

These texts informed the author, but are not cited in this report.

Abbreviation	Document
Buckley	MANAGING PEOPLE IN AUSTRALIAN PARKS - 3. RISK MANAGEMENT AND PUBLIC LIABILITY Ralf Buckley, Natasha Witting & Michaela Guest, CRC for Sustainable Tourism http://www.crctourism.com.au/BookShop/BookDetail.aspx?d=161
Dickson	INTERNATIONAL VISITORS TO AUSTRALIA: SAFETY SNAPSHOT 2003-05 Tracey J Dickson and Margot Hurrell, CRC for Sustainable Tourism http://www.crctourism.com.au/BookShop/BookDetail.aspx?d=555

4 Terms

Term	Meaning
N, NE, E, SE, S, SW, W, NW	Compass bearings, used to denote a face of the mountain
Coffey's Block	The large block identified in Coffey (Coonowrin) 1999 [1] on the NNW face, designated in Coffey's diagrams as "loose block"
Salmon's Leap, Mank Master, The Track, etc	(All climbing routes named in this report are according to Col Smithies' authoritative guide to climbs in the area [8].)
The Track or TT.	The original climbing route discovered by Harry Mikelsen in 1910 and used as the primary route until the 1960s. A little used and rubbly ascent route that climbs the NNE gully, eventuating in summiting through the gully up over the NNE shoulder (ref Col Smithies [8])
Salmon's Leap or SL.	The main casual ascent route used since the 1960s that climbs the S face eventuating in summiting from the SE shoulder (ref Col Smithies [8]). It usually requires first time climbers to tie into ropes. Frequent climbers tend to climb it without ropes comfortably.
Mank Master or MM.	A little used and awkward ascent route that climbs the NNW face, through a cave complex that travels behind Coffey's Block and out over the top of it, then eventuating in summiting through the gully up the NNE face (ref Col Smithies [8])

5 Purpose

The original purpose of the study undertaken in producing this report was "*to improve the body of knowledge pertaining to the incidence of rockfall on Mt Coonowrin*". This has certainly been accomplished, however that information is still largely only in the hands of the author and his research team.

A large quantity of photographic and video footage was gathered during the study phase, such that when it came to analysis and reporting it was found that there was more material data gathered than could be processed by the author in a timely manner to produce a comprehensive report about all aspects of the research done. As a consequence, this 2011 report is both historically late, in that the data pertains to the period 2007-2009, and the report's scope is limited to the topic of:

"What is the most significant information concerning the incidence of spontaneous rockfall at Coonowrin that can now be reported and that better informs the appointed land managers as to the safety of visitors to that location."

Other matters investigated and noted during the research, including but not limited to botanical and wildlife status, secondary geological significances of the location, historical significance of artefacts found, track erosion conditions, potential alternative track routing and cultural and heritage issues are withheld from this report for brevity and clarity.

6 Background

Mount Coonowrin ("Crookneck") is a freestanding spire of rock in the Sunshine Coast hinterland, and has been visited and/or climbed by members of the public for around 100 years from around 1890 to 1999.

In 1999 the area was closed to general access and listed as "restricted access". According to my investigations, limited permits have been granted since closure to:

- the SES for training and rescue,
- the local quarry for blasting vibration monitoring,
- the author of this study for the purposes of furthering the knowledge of rockfall risks on site.

The loss of general public access to this area is regarded by local wilderness clubs and interested members of the public to be of great concern, as the area is of unique natural beauty and historical significance, and access to the area was of irreplaceable importance to many people involved in local wilderness pursuits.

The closure was propagated by reference to a report prepared by a geological consultancy firm, Coffey (Coonowrin) 1999 [1]. The risk quantification in this report was prepared prior to the availability of the two more recent sources for wilderness risk management policy which have been used since that era for similar analyses - ANZECC 1998 [4] and AGS 2000 [5], as exampled in Coffey (Beerwah) 2006 [3]. The risk quantification undertaken for this report was constructed prior to Coffey (Beerwah) 2006 [3] being made available to the author, and it was found on examination that the risk quantification exampled in Coffey (Beerwah) 2006 [3] was in fact less detailed, and as such it was decided to leave the risk quantification in place without alteration until such time as a re-evaluation is warranted.

7 Methodology

The design of the study was based on the following.

Initially the Coffey (Coonowrin) 1999 [1] report was studied so as to understand what was already known about the location. It was identified that a full quantitative risk analysis had not been completed within that study, and that with advances in geomechanical engineering standards this was advisable so as to better inform the land management decisions.

A basic mathematical extension of the rockfall data provided within Coffey (Coonowrin) 1999 [1] was performed to ascertain whether the risk level was quantifiable as being within reasonably safe levels for access for the study team, if not the public. This theoretical calculation established that the theoretical risk level was classifiable as being safe enough for open public access based on the infrequency of rockfall incidents. The consequent probability of death to an individual due to random rock falls was calculated as being within a range equating to the chances of death occurring by snake bite, lightning strike or accidental death by prescribed drug use – between 0.2 - 2 in a million.

On the basis of this theoretical safety level, it was decided to make some first-hand observations to validate whether this theoretical safety level was supported by empirical observations, or whether observations might reveal a greater level of rockfall than expected from theory.

At this point a draft report was produced and presented to the QPWS land managers so as to demonstrate the probable safety level for a study team and to request permission to access the site to obtain first-hand observations that would support or oppose the theoretical risk calculation. Access was granted and this study progressed.

The following observations were made to assist confirmation of the risk level:

- Distant photographs of the overall rock faces were taken at interim time periods.
- Walks around the base of the cliffs were undertaken, looking for any fresh fall sites, and photographs taken.
- Ascent of the rock faces was undertaken to examine the areas denoted in Coffey (Coonowrin) 1999 [1] as “fresh rock fall” and “very high risk” to make first hand observations of the rock characteristics in those locations.
- Observation for any other evidence that might add value to the understanding of risk in that location.

The following analytical steps were undertaken to make value from the data and observations gathered:

- A comparison of the long distance photos of the cliffs was made over both long and short terms, so as to identify any rock that had changed from photo to photo and hence may indicate a rockfall location.
- A comparison of close distance photography records from time to time, for similar reasons.
- Calculations of number and size of rockfall quantities from these comparisons.
- Calculation of rockfall size and frequency based on rocks observed fallen to the ground.
- Comparison of these two observation-based rockfall frequency calculations to the theoretical rate of rockfall predicted by Coffey (Coonowrin) 1999 [1], to evaluate whether the observations support the theoretical rockfall rate.

8 Commentary on Existing Studies

The principal existing study is the one that was performed in 1999 (Coffey (Coonowrin) 1999 [1]) and which was used as the basis for the closure of the area to general access. This report is now dated in a number of ways and its formation and conclusions now warrant review, and the following basic observations can be made about its limitations.

Coffey (Coonowrin) 1999 [1] has the following limitations in its construction for informing this issue:

1 It does not include the recognised steps of a formal Risk Assessment as per guidelines provided by the Queensland Government [7] and as is generally accepted within other professional practices regarding Risk Analyses.

2 It does not include an attempt to calculate the numeric probability of rockfall as recommended in both AGS 2000 [5] and AGS 2007 [6], despite having included sufficient preliminary information to attempt such a calculation. AGS emphasises a need for numeric quantification of risks to be undertaken wherever possible (AGS 2000 [5]).

3 It was constructed on the basis of a snapshot of information taken in 1999, particularly that of photographs taken from a helicopter flight around the mountain and some walking party access to the base of the mountain. No first hand information was gathered above the cliff-line base, and no historic information was gathered from archival photographs of the peak's rock faces.

4 It does not attempt to identify the wide variety of access modes and utilisation purposes used by the general public, nor attempt to establish whether the risk probability for any of the existing user groups involved at the location is within an acceptable range for continued access. There is a reference to "rock climbing" which has no supportive data or argumentation as to why that specific activity attracts or induces a higher risk, particularly since it was not referred to in the works brief's scope.

5 It makes a single conclusion (shown below) regarding future utilisation of the cliff-line and summit areas recommending general closure, without having taken account of the above factors nor having researched or presented any assessment of the impact upon affected user groups of such a closure strategy.

> **6.4 Future Usage of Mount Coonowrin National Park**
>
> In general, it is considered that there is a High to Very High Risk of rock falls from the cliffs around Mount Coonowrin with a corresponding risk to members of the public accessing this area. It is recommended that the trail accessing the base of the cliffs be closed to the public and that the area be closed to rock climbing.
>
> Some alternative options to maintain the area for recreational purposes could include construction of a bush walks with viewing platforms around the lower slopes of the mountain.

6 The change in emphasis of the role of the "Engineering expert" from 1999 to 2006 via constraining the exercise to a provision of formal slope analyses is emphasised by the inclusion in Coffey Beerwah 2006 [3] of firstly a formal quantification of risk and secondly the following paragraph which emphasises the role of the engineering analysis moving from a "prescriptive" to "advisory" role.

> We highlight that in assessing the total risk there is no established criteria for the acceptance of loss of life. The total risk should however be considered in the context of other risks that all walkers may be subjected too, for example like being involved in a car accident while driving to the National Park itself or struck by a branch falling from a tree. Ultimately any decisions on risk acceptability (or tolerance) must be made by the Queensland Parks and Wildlife Service in the context of other risks associated with all of their other assets and their associated risks.

9 Update on the 1999 Risk Analysis

9.1 Risk Quantification Outline

The intention of this section is to numerically quantify the risk levels at Coonowrin. This was not undertaken in Coffey (Coonowrin) 1999 [1], and some of these methods were not required practice at the time those reports were undertaken. The intention is to inform the management process by making reasonable quantified risk statements with the assistance of standard measures and using reasonable engineering estimates of risk frequencies in line with the the approach used in the Australian Geomechanics Society's "Landslide Risk Management Concepts and Guidelines".

9.1.1 Method

To quantify the risk, the following process has been carried out for this report.

1. The rock fall characteristic and frequency is taken largely from the previous geological reports, especially Coffey (Coonowrin) 1999 [1]. Additional data is used to make engineering estimates when sufficient data is not effectively supplied by Coffey (Coonowrin) 1999 [1] and this is indicated where relevant in the body of the report.
2. The area of impact of a typical rockfall is estimated using reasonable principles of surface areas, trajectories and deflections of rock in motion.
3. Principle 2 above is used to estimate the gross area of at-risk land surface.
4. The gross area of a person's personal space at-risk is estimated.
5. The intersection of the above principles (1,3,4) gives the probability (in N per Million) that a person standing in an at-risk zone would suffer a fatal impact due to arbitrary rockfall during a single hour.
6. The different modes of access undertaken by persons (eg: walker, hiker, climber) are estimated, based on empirical data from the 1990s.
7. The duration of each of these access modes is estimated, based on empirical data from the 1990s.
8. The intersection of the above 3 principles (5, 6, 7) gives the probability (in N per Million) that a person undertaking a single trip of that type (eg: walker, hiker, climber) at Coonowrin would suffer a fatal impact due to arbitrary rockfall.
9. The frequency and number of participants of each of these access modes is estimated, based on empirical data from the 1990s.
10. The intersection of the above 2 principles (8, 9) gives the summary probability (in N per Million) that any one of all persons undertaking trips of each type (eg: walker, hiker, climber) at Coonowrin would suffer a fatal impact due to arbitrary rockfall in a single year.
11. Presentation of the data from principle 10 is used to calculate the gross risk undertaken by the department (in both N per Million and %) per year that there would probably be a fatal impact due to arbitrary rockfall at Coonowrin, the expected event recurrence (in N years) and the percent chance that such an event will occur during an administrative span of 20 years.

Note that "engineering safety factors" are deliberately not applied (multiplying figures by arbitrary safety constants eg: x2, with the objective being to design in a safety margin). This is so, because the resultant risk probabilities are only valued for significance in multiples of 10, ie:

Activity (undertaken during a whole year, typical participation rates)	Risk Probability per year (per million)	Risk Probability per year (N:1EM)
Meteorite strike	0.001 per million	N:1,000,000,000
(no examples available)	0.01 per million	N:100,000,000
Venomous plants/animals / lightning strike	0.1 per million	N:10,000,000
Eating food (and choking) / prescribed drugs	2 per million	N:1,000,000
Homicide victim, swimming accidents/drownings	20, 50 per million	N:100,000
Motor vehicle travel	145 per million	N:10,000
Cancer, smoking, US military fatality rate in IRAQ (various analyses differ)	1800, 5000, 1500 to 7500 per million	N:1,000
Scaling above 8000 metres on Everest (various analyses differ)	1:100 to 1:20	N:100
A single game of "Russian Roulette"	1:6	N:10

Table 1. Understanding basic risk probabilities

Hence if reasonable engineering estimates are made, it may be argued under examination that the estimates may vary in either direction, but usually no more than by a factor of 2-5, therefore the final risk probability will still be in the same basic magnitude range, ie: N per million, N per 100,000, N per 10,000, or N per 1000 etc.

Note that these are often written using a variety of shorthand notations, such as by using the Exponential notation N:1E6 (N per million), N:1E5 (N per 100,000), N:1E4 (N per 10,000), N:1E3 (N per 1000). AGS recommendations on Acceptable Risk Probabilities use the notations 1E-6, 1E-5, 1E-4, to show their recommended risk cut-offs: 1:1,000,000, 1:100,000, 1:10,000.

[For mathematicians inspecting this report: I recognise that the correct means of summing probabilities is by use of the formulae 1-(1-probability)no of trials or 1-((1-probability#1)x(1-probability#2)) It can be demonstrated that at probabilities less than 1 per 1000, there is only an insignificant error in using a simple sum of probabilities, and therefore summation is used for ease of application. Summing risks above 1% (ie: in the range of 1% to 100%) should be done using the correct formulae described above to avoid more significant errors.]

9.2 Establishing Natural Hazard Mechanisms and Quantities

9.2.1 Quantification of Hazard Mechanisms and Frequencies

For the purposes of this study, the data from Coffey (Coonowrin) 1999 [1] forms the primary source of data regarding the risks associated with natural land slide and rock fall.

The four identified rock fall mechanisms were:

1 **Singular block fall on the South and East faces** – to a quantity established as 3 to 4 blocks each of **volume 0.5 m^3** per year. (ref: Coffey (Coonowrin) 1999 [1] Section 6.2 "First mode of failure")
For the purposes of this Risk Analysis we will use the simple average "**3.5 falls per year**".

2 **Singular block fall on the North and West faces –** to a quantity estimated as **1 block each of volume 0.5 m^3 per year.** (not identified by Coffey (Coonowrin) 1999 [1], added for completeness) There is no evidence in Coffey (Coonowrin)

1999 [1] to substantiate the fall rate in this mode, however it is included at a conservative rate for completeness.

3 **Minor landslide of a bulk of earth and/or rock on the North and West faces** – volumes ranging from **1m^3 to 1,500 m^3**. (ref: Coffey (Coonowrin) 1999 [1] Section 6.2 "Second mode of failure") There are historic observations of minor landslides available from literature and living and recent memory. The local SES and other user groups reported knowledge of two landslides in living memory:

- 1930s: SES: "we had talked with a local farmer who had said that there was one landslide before the war" and again that "Bill Fullerton mentioned that there was one in the '30s".
- 1960s: SES: "In the mid '60s there was a major fall on the North East which altered "The Track" making it less safe to travel, after which Salmon's Leap (South) became popular instead."
- 1990s: There is knowledge held by the author and others of a third rock fall in the 1990s: a part of the climb known as Mank Master (North West face) was found to have altered, and this may be linked to local residents commentary about rockfall in that era (claimed at the time to be linked to quarrying).

For the purposes of this Risk Analysis we will use the simple average of the spans between the 3 reasonably certain events: "**1 fall per 30 years**".

4 **Major landslide of a bulk of earth and/or rock on the North and West faces** – volumes ranging from **1m^3 to 40,000 m^3**. (ref: Coffey (Coonowrin) 1999 [1] Section 6.2 "Third mode of failure") The last known fall of this kind was cited as being of age 1,000 years to 10,000 years. (ref: Coffey (Coonowrin) 1999 [1] Section 7, par 4).
For the purposes of this Risk Analysis we will use the logarithmic average to satisfy a Poisson distribution of the time estimate's error: "**one per 3160 years**".

A further search for evidence of quantification of the North and West faces' modes of failure yielded the following observations:

1 The photographs taken in 1999 have been compared with photographs taken in 2007/2008 to determine whether any new rock has fallen. There is some evidence of minor rockfall and this is examined in detail in the later section *Long Distance Photographic Comparison*, however it does not amount to a quantity and frequency greater than that expected by Coffey (Coonowrin) 1999 [1]. Furthermore the brown colouration noted in 1999 as evidence of recent rockfall is still present, evidence that the brown colouration does not signify recency in terms of "within the last ten years", but of a period significantly greater than that.

2 The photographs were compared to archive footage of the area from public sources. Preliminary comparisons of the areas photographed in 1999 with photos taken in 1929 show that the areas cited as "Recent rock falls (brown patches and overhangs)" are also evident in 1929 in the same rock shape configuration. This further extends the age of "brown coloured" areas of rock to being related to rock fall at least greater than 80 years old so an age of fall could be given as "fewer than 1 falls in 70 years" [ed: The calculations performed here originally used 70 years, when the photos were thought to be dated in the 1930s and have not been redone after the date was noticed to be 1929. This improves the safety margin by some 12% so it was not redone for lack of time to recompile the calculations.]. Particularly the areas shown in Coffey (Coonowrin) 1999 [1] plate 10 marked

"recent rock fall", and the areas marked "very high risk" shown in plates 23 and 24 high on the North West corner also visibly have the same basic rock shape outlines in 1929.

3 This is given as evidence that the falls related to these rock shapes are older than 80 years as a reasonably ascertained scientific fact, and therefore the qualification of the brown colouration in general as evidence of "recent rock fall" is only indicative of "recent" as being in terms of within recent centuries or millennia, not in terms of recent years or decades. The chosen range of rock fall rate for minor land slips on the North West faces is one per 30 years in accordance with the local historic knowledge and this fits comfortably together with this observation, but could be extended substantially.

9.2.2 Quantification of Hazard Impact Areas

Each of these four failure modes can be estimated to have different destructive impact areas (measured in m^2) where the rock fall strikes the accessible area of the mountain.

This can then be used to calculate a probability that a rock fall event will overlap with an access timeline for each of the identified modes of access.

To achieve a reasonable calculation some understanding of rock fall mechanics and trajectory mathematics has to be included.

For the purposes of this study, a single block falling on the South and East faces is averaged to fall from half height on the plug (60m), and (tumbling/bouncing) impact half of the fall path (totalling 30m) in a 1m wide strip down the wall during descent and then land away from the wall (in the forest on the conic base) and describe a path in the forest prior to coming to rest. Hence, the block's bounces/tumbles on the wall are estimated to impact a total of $30m^2$ and the impact area in the forest is estimated to be a line of 1m wide by 50m long giving 50 m^2 impact area in the forest.

Note that these estimates have been increased from lesser estimates on the advice of an auditing civil engineer, and are considered to be generously concessionary to safety margins, if anything. Later research of observations of the path of fallen pillars (see: *Fallen Rock Around the Skirt* on page 85) on site found the typical rolling path to be on average 10m. Better estimates could be established by mathematic modelling, however the impact areas are thought to be more likely to also reduce under such analysis, and could only mathematically increase by a maximum factor of "x 2" otherwise, which is not significant in relation to risk probabilities (as demonstrated, they step in significance by "orders of magnitude", ie: x10.) All up, the numbers used are considered to be generous on the side of safety by a probable factor of x5, and so the final risk to visitors may probably be less by a factor of x5.

Since there are no access tracks in the forested area on the North and West and no record of access in these areas, the impact into the forest is not included for calculation, only the impact on the narrow walking path that exists at the very base of the cliff faces.

For the purposes of this study, a single block falling on the North and West faces is taken to replicate the fall path of that assessed above for the South and East faces. The impact area in the forest is taken to be a 2 m^2 area as we are only considering the track path.

For the purposes of this study, a minor land slip on the West and North faces is expected to impact upon the entire wall beneath the fall, and along a greater area of the track at the foot of the cliff. To allow hazard area calculations, a slip is estimated to impact an averaged trapezoidal area with width of 2 metres wide at the top and 10 metres wide at the base and vertically half the height of the plug (60m), totalling 360 m^2 of the cliff face and 10 m^2 of the track at the base.

For the purposes of this study, a major land slip on the West and North faces is expected to impact upon the entire wall beneath the fall, and along a greater area of the track at the foot of the cliff. To allow hazard area calculations, a slip is estimated to impact an averaged trapezoidal area with width of 10 metres wide at the top and 20 metres wide at the base and vertically half the height of the plug (60m), totalling 900 m^2 of the cliff face and 20 m^2 of the track at the base.

This is summarised as follows:

Hazard Mechanism	Hazard Frequency	Impact area – cliff	Impact area - forest	Comment
Single Blocks (S&E)	3.5 / year	30 m2	50 m2	Radially.
Single Blocks (N&W)	1 / year	30 m2	2 m2	Area along the cliff base in a 1m wide strip.
Minor Land Slip (N&W)	1 / 30 year	360 m2	10 m2	
Major Land Slip (N&W)	1 / 3160 year	900 m2	20 m2	

Table 2. Hazard Mechanisms' Frequencies and Impact Areas

9.2.3 Quantification of Impact Probability

This is the overlap between Impact Area and Access Path.

The total potential hazard area is also necessary to complete this stage of calculation. This calculation is not fully included in the Coffey Beerwah 2006 [3] report, where every impact is assumed to coincide with the walking track and the calculation is reduced to the combination of the fall frequency and the probability of a person being at that point in the track. This analysis seeks to more fully calculate the risks by determining the probability that a fall will in fact overlap with a person's walking path.

To find this the land area is reduced to two basic mathematic areas: a cylinder (the cliff-face plug) and a truncated cone (the forested base). Also the mountain is now split vertically into 2 equal pieces North and West faces (NW) and South and East faces (SE), as they have distinctly different hazard and access profiles

The at-risk areas of the cylindrical plug (using pi x diameter) are found using the following data:

Property	Value
Plug base diameter	130 m
Height of plug	120 m
Circumference	408 m
Half Circumference	204 m
Surface Area	49009 m2
Half Cylinder SA	24504 m2

Table 3. Basic calculations of vertical cliff's dimensions

The at-risk areas of the conic base (using pi x slant height x radius and deducting the peak of the cone) are found using the following data:

Property	Value
Slant angle	45deg
Plug base diameter	130 m
Slant height of forest	350 m
Vertical height of forest	247 m
Lateral distance of forest	247 m
Full Cone Radius	312 m
Full Cone Height	312 m
Full Cone Slant Height	442 m
Full Cone Surface Area	433840 m2
Cliff cone radius	65 m
Cliff cone height	65 m
Full Cone Slant Height	92 m
Cliff Cone Surface Area	18771 m2
Cropped Cone Surface Area	415069 m2
Half Cropped Cone Surface Area	207535 m2

Table 4. Basic calculations of forested slope's dimensions

Summarising the at-risk areas of the mountain's surface:

Hazard Mechanism	Total Hazard Area - cliff	Total Hazard Area - forest	Comment
Single Blocks (S&E)	24504 m2	207535 m2	350m radially from cliff.
Single Blocks (N&W)	24504 m2	204 m2	Area along the cliff base in a 1m wide strip.
Minor Land Slip (N&W)	24504 m2	204 m2	
Major Land Slip (N&W)	24504 m2	204 m2	

Table 5. Total At-Risk Areas

Combining data from tables 2 and 5, the probability of being caught in the impacted area if a person happens to be present at the exact time of a fall event (using impact area / total risk area) is:

Hazard Mechanism	Event/access overlap probability - cliff	Event/access overlap probability - forest
Single Blocks (S&E)	1.22E-03	2.41E-04
Single Blocks (N&W)	1.22E-03	9.79E-03
Minor Land Slip (N&W)	1.47E-02	4.90E-02
Major Land Slip (N&W)	3.67E-02	9.79E-02

Table 6. Probability of being struck if present during a fall

9.2.4 Quantification of Basic Risk Probability

The risk probability can now be calculated in terms of "risk probability per hour of access time" which is estimated to be the most functional form for performing further calculations. (A translation into "per million person years" which is used by other reporters will also be provided for comparison.)

Hence the probability during any full hour of access time in each risk zone (using hazard frequency and impact probability) is:

Hazard Mechanism	Hazard Probability (events per hour)	Risk Probability - Cliff	Risk Probability - Forest
		(per hour of access)	
Single Blocks (S&E)	4.00E-04	4.89E-07	9.63E-08
Single Blocks (N&W)	1.14E-04	1.40E-07	1.12E-06
Minor Land Slip (N&W)	3.81E-06	5.59E-08	1.86E-07
Major Land Slip (N&W)	3.61E-08	1.33E-09	3.54E-09
All Fall Types (N&W)	1.18E-04	1.97E-07	1.31E-06

Table 7. Probability of being present during a fall and being struck

Converting this Risk into "N per Million" for readability and ease of recalculation:

Hazard Mechanism	Risk Probability - Cliff	Risk Probability - Forest
	(N/Mill per hour of access)	
Single Blocks (S&E)	0.489	0.0963
All Cited Fall Types (N&W)	0.197	1.31

Table 8. Probability of being struck by a random rockfall per hour of access (N / Million)

9.3 Establishing Risk Presented to any Individual

9.3.1 Access Mode (Visitor Type) Identification

The next step in this risk analysis is to qualify and quantify the modes of access, that is the distinct ways in which people visit Mt Coonowrin. The following observations were made during a sequence of around 35 personal visits by the author during the 1990s.

There appear to be 5 main modes of public access, termed as follows for the purposes of this report:

1 Rockclimbers ("Climbers") – A high degree of personal skill, fitness, equipment and training. The objective of the access is to complete a technical sequence of climbing, perhaps completing an ascent of the mountain, but not necessarily. Climbing equipment is often used as a life-preservation mechanism, due to the high probability that a climber will fall during attempt. Climbers are, by nature, continuously managing a complex matrix of risks and are usually highly aware of hazard modes associated with cliff faces. On Coonowrin, ascents are usually made via the sets of climbs mapped out on the SE, E and NE faces, due to the strength and reliability of the rock in these areas. These are all graded above 10 in the Australian climbing grades system.

2 Scramblers (elsewhere has been variously termed "mountaineer", "mountain climber", "hill climber", this is an uncommon terminology locally due to the absence of any authentic, full-range mountaineering sites in South East Queensland) – A high degree of personal skill and fitness and some sound basic equipment skills. The essential objective of the access is to complete an ascent of the mountain, perhaps by using a unique or interesting route. Climbing equipment is sometimes used as a life-preservation mechanism, depending on the confidence of the Scrambler compared to the route. Scramblers manage a less complex matrix of risks and are usually mostly aware of hazard modes associated with cliff faces. On Coonowrin, ascents are usually made via Salmon's Leap (S) or The Track (N), or more adventurous ascents are available via Clark's Gully (S), West Face Route (W), North West Route (NW), or Mank Master (NW). These are all graded below 10 in the Australian climbing grades system.

3 Hikers – (More skilled bushwalkers, trekkers, trampers) A high degree of personal skill and fitness but possibly lacking essential equipment skills. The essential objective of the access is to hike to and/or around the mountain without completing an ascent. Climbing equipment is not usually used for hiking, but may be employed in some instances to safeguard a more hazardous traverse. Hikers manage a basic array of wilderness risks and may or may not be aware of hazard modes specifically associated with cliff faces. On Coonowrin, Hikers will usually walk to the base of Salmon's Leap (S) and rest for a time; then some will walk around to the North side, some may circle the peak, and the rest will retire without proceeding.

4 Bushwalkers – (Less skilled bushwalkers, day-trippers, family groups) A low degree of personal skill and fitness and probably lacking any significant equipment skills. The essential objective of the access is to walk comfortably near to the mountain, perhaps to obtain a view, without completing any difficult ascent. Bushwalkers may only have basic understanding of wilderness risks and will usually not be aware of hazard modes specifically associated with cliff faces. On Coonowrin, Bushwalkers will usually walk to below the short slab 20m below Salmon's Leap (S), and rest for a time, then some will ascend to the base of Salmon's Leap (S) then rest and retire, and the rest will retire without proceeding.

5 Local Residents ("Locals") - A moderate degree of personal skill and fitness but possibly lacking any significant equipment skills. The essential objective of the access is to walk up to and around the mountain, enjoying views and exercise, without completing a full ascent. Locals may have a range of understanding of wilderness risks and can often be aware of hazard modes specifically associated with these cliff faces due to personal study. On Coonowrin, Locals will usually walk to the base of the cliff line, then circumnavigate the peak and retire. Due to proximity and familiarity this would be expected to be undertaken much more rapidly than other accessors.

There are estimated to be 3 additional modes of access, which are logically present in low volumes, without specific data available to support that conclusion:

6 QPWS Rangers - A high degree of personal skill and fitness and some sound basic equipment skills. The essential objective of the access is to audit park usage. Climbing equipment is not generally carried and full ascents are not undertaken without a purpose. Rangers manage a more complex matrix of risks than most accessors, as they are required to assess the risk matrix of the public's activities and are mostly aware of hazard modes associated with cliff faces. On Coonowrin, ascents are rarely made beyond Salmon's Leap (S) but all other areas are occasionally traversed for audit.

7 Emergency Services – Non-Cliff-line – A very high degree of personal skill, fitness, equipment and training. The essential objective of the access is to perform or audit personal rescues or fire situations. Climbing equipment is not generally carried and full ascents are not generally undertaken. Emergency Services manage a more complex matrix of risks than most accessors, as they are required to assess the risk matrix of the public's activities in a rescue situation and are usually aware of hazard modes associated with cliff faces. On Coonowrin, ascents are rarely made beyond Salmon's Leap (S).

8 Emergency Services – Cliff-line – A very high degree of personal skill, fitness, equipment and training. The essential objective of the access is to perform personal rescues of stranded accessors. Climbing equipment is usually integral to the task. Cliff-line Emergency Services manage the most complex matrix of

risks, as they are required to assess the risk matrix of the public's activities in a vertical rescue situation and are essentially aware of hazard modes associated with cliff faces. On Coonowrin, ascents are usually made via Salmon's Leap (S), for the purposes of rescue on other faces from above.

9.3.2 Quantification of Access Profiles

These individual area risk probabilities can now be used to calculate the predicted risk to an individual engaged in the identified access modes.

The following observations of reasonable average access durations were made during around 35 visits made in the 1990s:

Access Mode	Time spent on the SE Cliff (hours)	Time spent in the SE Forest (hours)	Time spent on the NW Cliff (hours)	Time spent in the NW Forest (hours)	Comment
Rockclimbers	4	2	0	0	Activity confined to SE, E and NE faces, mostly separated from public walking track
Scramblers (S & E faces)	1	1	0	0	Most common Scrambling ascent – SL ("Salmon's Leap")
Scramblers (W & N faces)	0.5	1	3	0.5	Ascender walks anticlockwise from SL and returns via SL at end of ascent
Hikers	0.75	1	0	0.25	Time is spent standing at base of cliff
Bushwalkers	0.5	2	0	0	
Local Residents	0.25	0.5	0	0.25	Assumed to walk all the way around base
QPWS Rangers	0.25	1	0	0.25	Time is spent at base of cliff
ES – Non-Cliff-line	1	2	0	0.25	
ES – Cliff-line	2	1	2	0.25	

Table 9. 1990's Access mode times estimate

9.3.3 Quantification of Individual Risk Probability

The risk probability can now be calculated in terms of "risk probability per access mode" which is estimated to be the most accessible and functional form for departmental and public interpretation, and for translation into accumulated departmental risk. A translation into "per million person years" which is used by other reporters will also be provided for comparison.

The following calculations of Individual Risk Probability per Access Mode can be made:

Access Mode	Risk Undertaken on the SE Cliff (N/Million)	Risk Undertaken in the SE Forest (N/Million)	Risk Undertaken on the NW Cliff (N/Million)	Risk Undertaken in the NW Forest (N/Million)	Total Risk Undertaken per access (N/Million)
Rockclimbers	1.96	0.19	0	0	**2.15**
Scramblers (S & E)	0.49	0.10	0	0	**0.585**
Scramblers (N & W)	0.24	0.10	0.59	0.65	**1.59**
Hikers	0.37	0.10	0	0.33	**0.790**
Bushwalkers	0.24	0.19	0	0	**0.437**
Local Residents	0.12	0.05	0	0.33	**0.497**
QPWS Rangers	0.12	0.10	0	0.33	**0.546**
ES – Non-Cliff-line	0.49	0.19	0	0.33	**1.01**
ES – Cliff-line	0.98	0.10	0.39	0.33	**1.80**

Table 10. 1990's Individual Risk Probability per Access Mode

The following estimates are made of the frequency of access per single person in each of the access modes, and consequent typical risk undertaken per year. (see section 4.7)

Access Mode	Typical Access count per year per person	Total Risk Undertaken per year (N/Million)
Rockclimbers	2	**4.30**
Scramblers (S & E)	2	**1.17**
Scramblers (N & W)	2	**3.17**
Hikers	1	**0.79**
Bushwalkers	1	**0.44**
Local Residents	**80**	**39.79**
QPWS Rangers	6	**3.27**
ES – Non-Cliff-line	2	**2.02**
ES – Cliff-line	1	**1.80**

Table 11. 1990's Total risk estimates for individuals in each access mode

The risk taken by **local residents** per year is much higher than all other modes due to the frequency of access reported (locals taking a "daily constitutional" walk around the base of the mountain), however it falls within the **"tolerable range" for "existing slopes"**, according to the AGS (2007) [6] guidelines. All the **other modes** of access fall within the **"acceptable" range for "existing slopes"** according to the AGS (2007) [6] guidelines.

As an aid to understanding of the comparative risks presented, the following table can be drawn up (regarding the risk of fatality due to natural rock fall at Coonowrin)

Activity causing Fatality	Total Risk Undertaken per year (N/Million)
Meteorite strike	0.001
Venomous plants/animals / lightning strike	0.1
Coonowrin RRF - Bushwalkers	**0.4**
Coonowrin RRF - Hikers	**0.8**
Coonowrin RRF - Scramblers (S & E)	**1.2**
Coonowrin RRF - ES – Cliff-line	**1.8**
Taking prescribed drugs	2
Coonowrin RRF - ES – Non-Cliff-line	**2.0**
Falling objects (domestic, urban, etc)	*3*
Electrocution (non-industrial)	3
Coonowrin RRF - Scramblers (N & W)	**3.2**
Coonowrin RRF - QPWS Rangers	**3.3**
Coonowrin RRF - Rockclimbers	**4.3**
Aircraft travel - Accidents	10
Fires and Accidental Burns	10
Accidental Poisoning	18
Homicide	20
Train travel (over an entire year)	30
Playing rugby / owning firearms	30
Coonowrin RRF - Local Residents (80 visits/yr)	**39.8**
Swimming	50
Accidental falls (domestic, urban, etc)	60
Motor vehicle travel (over an entire year)	145
Drinking alcohol (all fatal consequences)	380
Motorcycle use (Canadian study)	100-1000
Cancer	1800
Smoking	5000

Coonowrin RRF = Random Rock Fall at Coonowrin

Table 12. Risk Comparison (Other items primarily added from D.J Higson, Risks to Individuals in NSW and in Australia as a Whole, ANSTO, July 1989)

9.4 Establishing Risk Presented to QPWS for all Visitors

9.4.1 Quantification of Access Mode Volumes

For this I have relied upon a reasonable volume of anecdotal evidence provided by individuals from the climbing and bushwalking fraternities who have been frequent accessors during the 1990s and earlier.

This data could be improved if access is re-established by performing access volume studies - counting and surveying accessors on sample days to yield a statistically significant database.

Access Mode	Group Frequency	No in Group	Span of activity /yr	Accesses /yr
Rockclimbers	1 / month	2	8 months	16
Scramblers (S & E)	2 / week	4	8 months	272
Scramblers (N & W)	2 / year	2	12 months	4
Hikers	1 / week	4	8 months	136
Bushwalkers	4 / week	4	6 months	400
Local Residents	2x2 / week	2	10 months	320
QPWS Rangers	1 / month	1	12 months	12
ES – Non-Cliff-line	2 / year	10	12 months	20
ES – Cliff-line	1 / year	4	12 months	4

Table 13. 1990's Access volumes estimate (1990's visit rates, uncontrolled access)

9.4.2 Quantification of Accumulated Risk to QPWS (pre 1999)

The previous data can be converted into an accumulated risk taken by the department in permitting general access.

Access Mode	Accesses /yr	Total Individual Risk Undertaken (N/Million per access)	Dept Risk Undertaken (N/Million per yr)	Expected Event Recurrence (years)
Rockclimbers	16	2.15	34.4	29082
Scramblers (S & E)	272	0.59	159.2	6280
Scramblers (N & W)	4	1.59	6.3	157653
Hikers	136	0.79	107.5	9306
Bushwalkers	400	0.44	174.8	5720
Local Residents	320	0.50	159.2	6283
QPWS Rangers	12	0.55	6.5	152757
ES – Non-Cliff-line	20	1.01	20.2	49571
ES – Cliff-line	4	1.80	7.2	139236
TOTAL RISK TO QPWS			**675**	**1481**

Table 14. Predicted accumulated risk of fatality (1990's visit rates, uncontrolled access)

The final cumulative risk figure for QPWS covering all accessors is 675 per million or such that one would expect one such fatality as a "once every 1481 years" event.

This can be converted into an accumulated % risk taken by the department during a single administrative span of 20 years duration as follows:

Access Mode	Dept Risk Undertaken (% per 20 yr span)
Rockclimbers	0.07%
Scramblers (S & E)	0.32%
Scramblers (N & W)	0.01%
Hikers	0.21%
Bushwalkers	0.35%
Local Residents	0.32%
QPWS Rangers	0.01%
ES – Non-Cliff-line	0.04%
ES – Cliff-line	0.01%
TOTAL RISK TO QPWS (20 years)	**1.35%**

Table 15. Predicted expectation that a fatality will occur in a 20 year administrative period (1990's visit rates, uncontrolled access)

Therefore there is a 1.35% probability that a fatality would occur due to random rock fall during a single administrative span of 20 years duration, given that a resumption of uncontrolled access were to resume at 1990's levels.

This fits with the observed data that there is no record of a fatality due to random rock fall in the entire 100 year history of post-settlement access to the area and no recognition of any such events in the well-known indigenous folklore.

Records of fatalities provided by the SES indicate that all known incidents both fatal and otherwise in the last 44 years, since 1963, have been the result of personal error by the injured visitor.

10 Correlation of Theory to Observations

10.1 Long Distance Photographic Comparison

These comparisons were made to establish whether there was evidence of rockfall over both long and short periods using photos available from historic records and photos taken during the study. The examinations intend to find visual mismatches as evidence of possible or probable rockfall. Some of this task is accomplished by looking instead for significant visual matches of key features, with the implication that the surfaces would therefore be shown to be largely unchanged over the period.

Note that these graphic comparisons were performed by the same author, but over a long time in numerous working sessions. As a result the techniques used to examine and annotate the images varied over the course of the study, resulting in the obvious variations in the following images' annotations. Once superior techniques were identified, there was not enough time or energy to re-evaluate all the work done to date. Hence the analysis here is inconsistent in presentation, but the intention and ultimate consequence is consistent regardless.

10.1.1 Historic (80 year) Comparisons

These comparisons were made to establish whether there was evidence of significant rockfall over the last century. The comparisons are between photos taken in 1929, and photos taken 70 to 80 years later during 1999-2009. These photos were supplied from Mike Meadows' archive and are dated 1929.

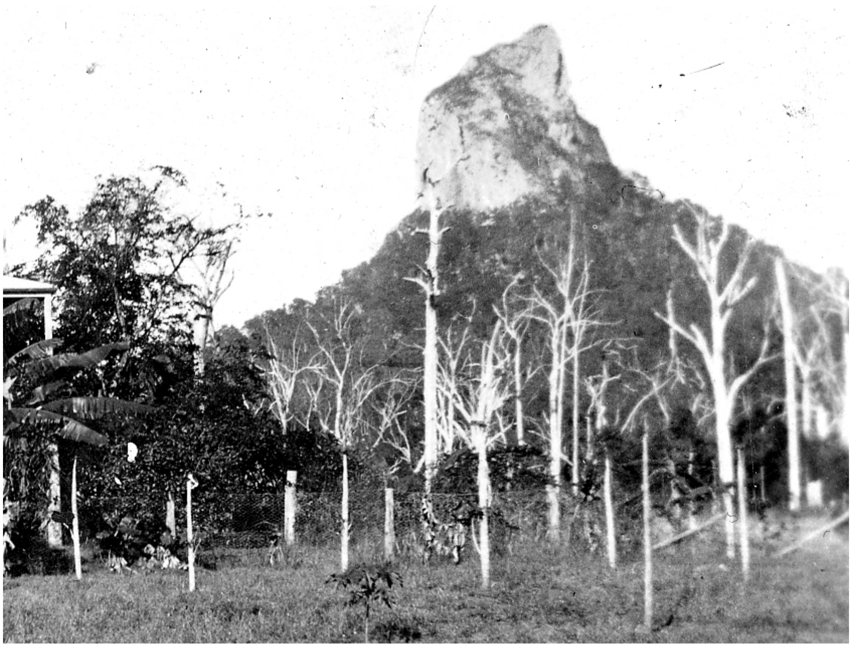

Figure 1. North Face, 1929 (image from Mike Meadows' collection)

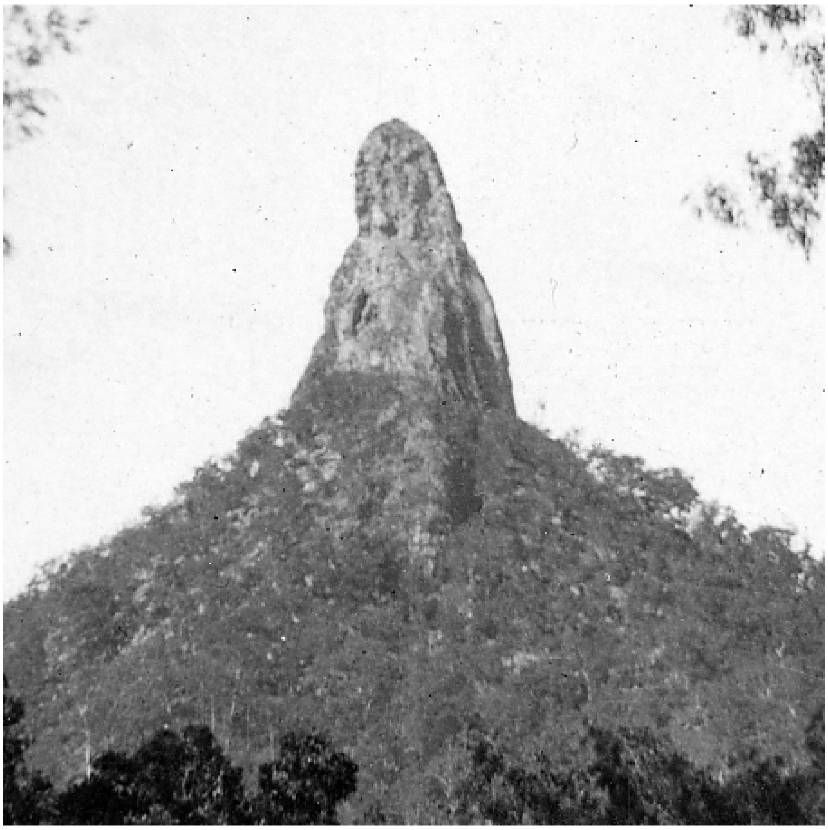

Figure 2. West Face, 1929 (image from Mike Meadows' collection)

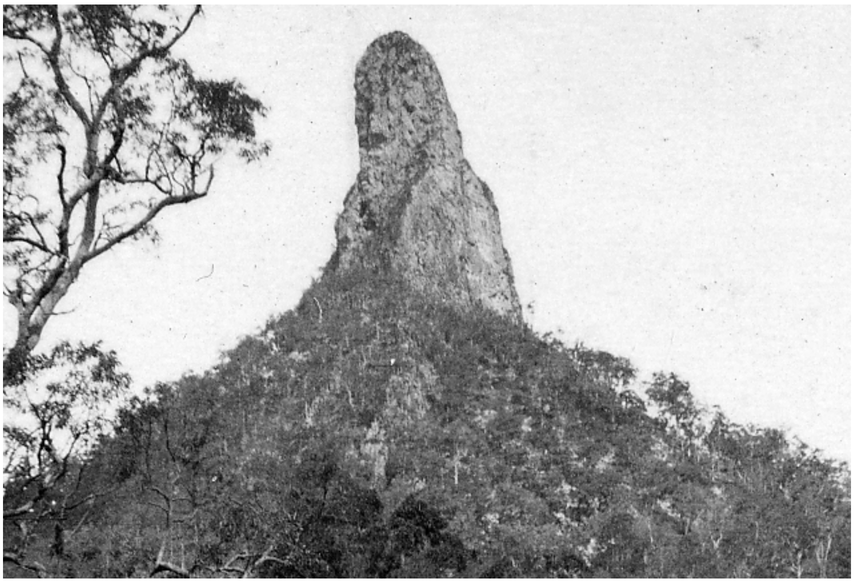

Figure 3. West-South-West Face, 1929 (image from Mike Meadows' collection)

10.1.1.1 West Face – Overall Profile – 1929-2007

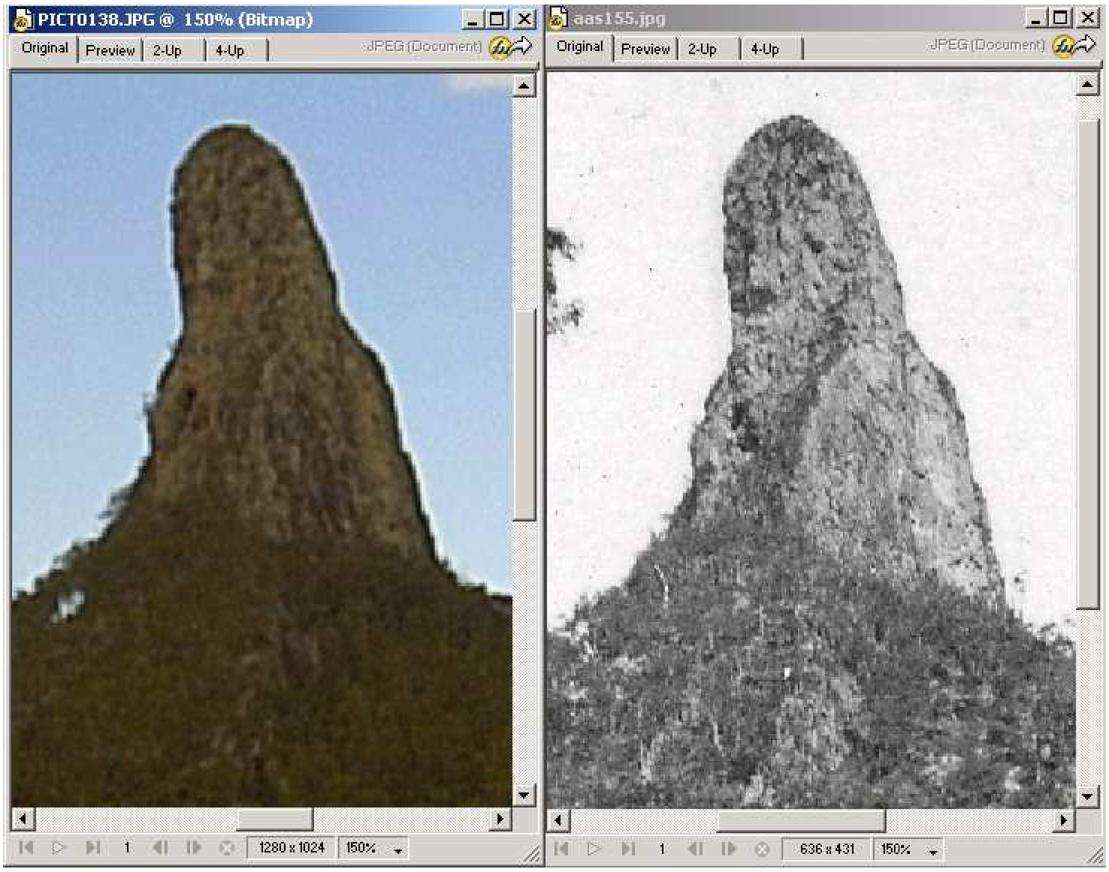

Figure 4. West Face - Overall Profile – 2007-1929 (second image from Mike Meadows' collection)

(Note that the older photo is on right side, all other photos in this report are the reverse orientation – older on the left)

Overall, Figure 4 identifies that over the past 80 years, there has been little identifiable by way of a major profile change on the West face. This is examined in more detail in the following analysis of close-ups of the face.

10.1.1.2 West Face Peak Detail – 1929-2008

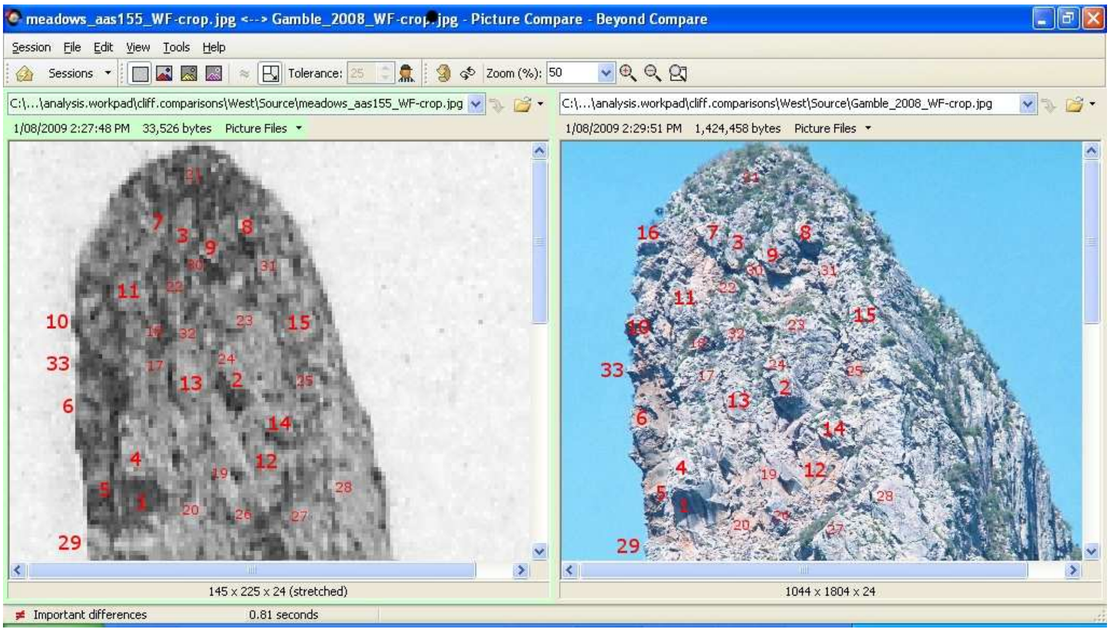

Figure 5. West Face Peak - Matched Features - 1929-2008 (first image from Mike Meadows' collection)

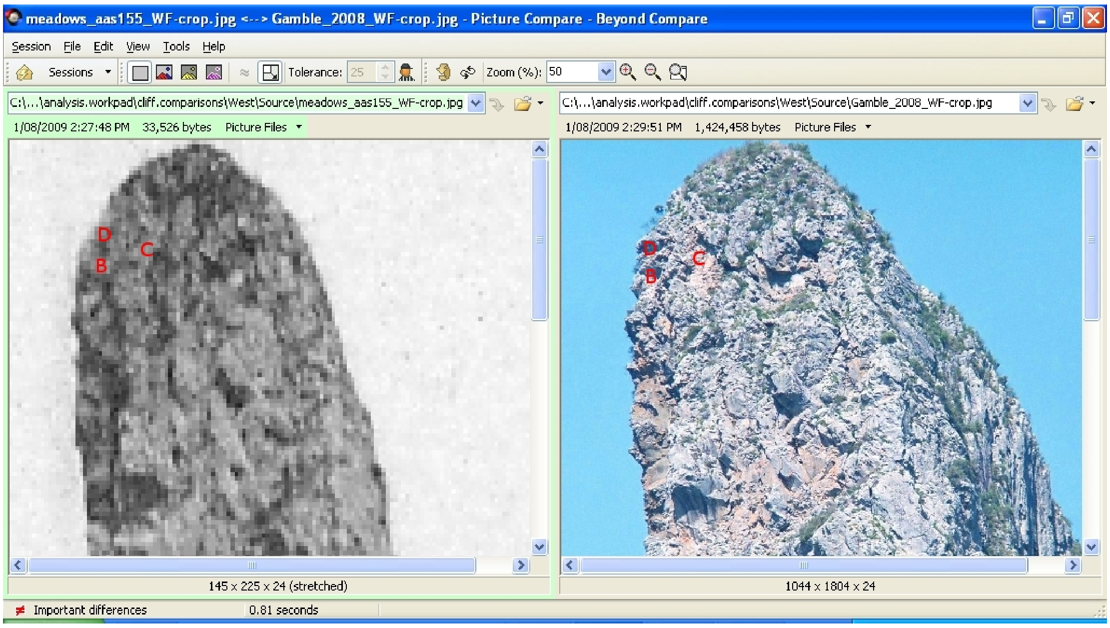

Figure 6. West Face Peak - Unmatched Features - 1929-2008 (first image from Mike Meadows' collection)

Figure 5 shows the specific rock shapes identified as matching, validating that the feature and any underpinning rock surface has not changed over the last 80 years.

Figure 6 shows the specific visual anomalies that were found in this section of the West face during the examination that may indicate the presence of a rock fall site that occurred sometime during the last 80 years.

Objects B, C and D don't seem to match, indicating possible one-off rock fall sites.

Of particular importance is the point of there being a close match found on the left side of the West face about ¾ of the way up the mountain. This is the area that was identified by Coffey (Coonowrin) 1999 [1] as "recent rock fall" as characterised by the "brown rock" areas (note matched objects 10, 33 and 6, and 20, 19 and 12 in Figure 5). The implication is that this "brown rock" area does not appear to have suffered a rock fall in the last 80 years and therefore "recent rock fall" does not mean a fall within the last 80 years at the very least.

10.1.1.3 West Face Mid-Height Detail – 1929-2008

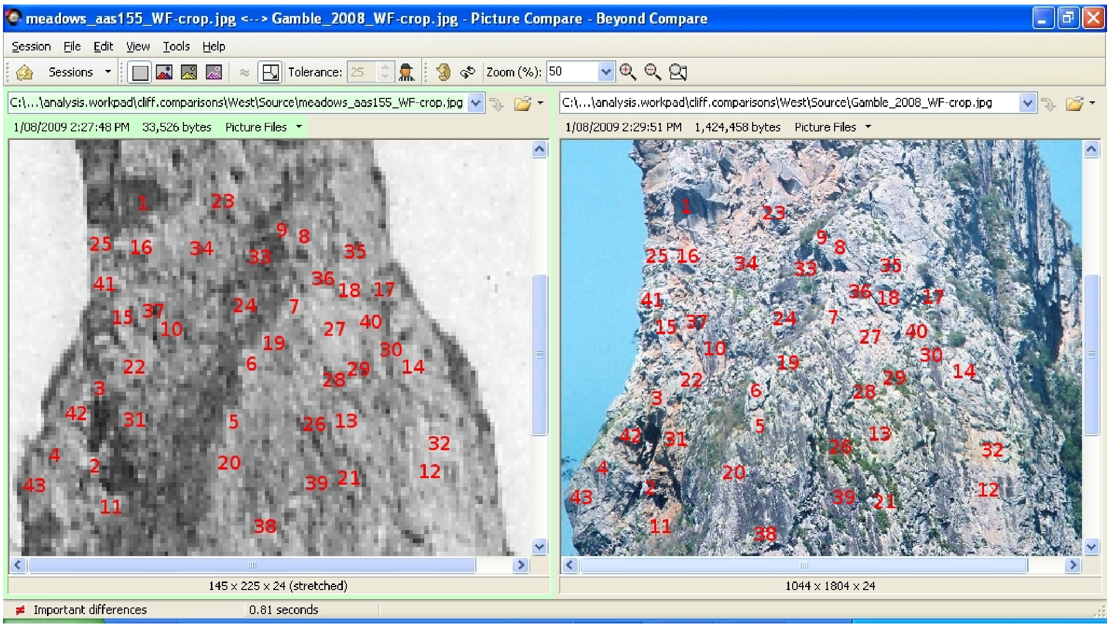

Figure 7. West Face Mid-height - Matched Features - 1929-2008 (first image from Mike Meadows' collection)

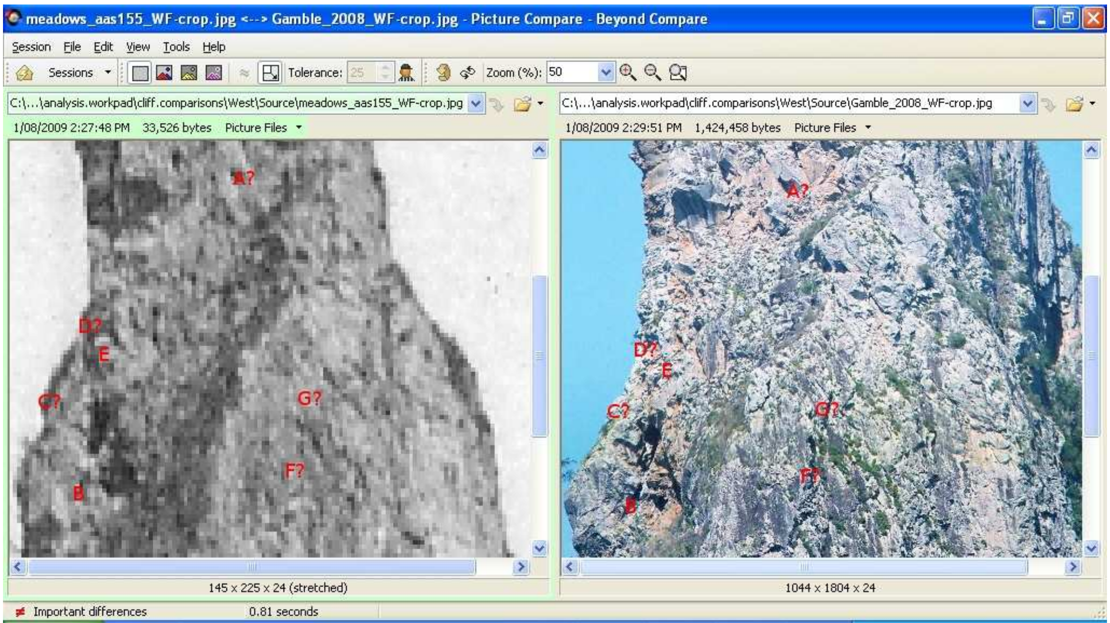

Figure 8. West Face Mid-height - Unmatched Features - 1929-2008 (first image from Mike Meadows' collection)

Figure 7 shows the specific rock shapes identified as matching, validating that the feature and any underpinning rock surface has not changed over the last 80 years.

Figure 8 shows the specific visual anomalies that were found in this section of the West face during the examination that may indicate the presence of a rock fall site that occurred sometime during the last 80 years.

Objects A, D and E don't seem to match, indicating possible one-off rock fall sites. Object C could be a fall site, but is just as likely to be a consequence of the photography angle. The opening up of the shadow at B is on the slip plane of Coffey's block and could indicate the movement of rock from that site over the period. The opening up of the shadow at F and G could indicate a line of instability in the rock on that surface.

10.1.1.4 West Face Base Detail – 1929-2008

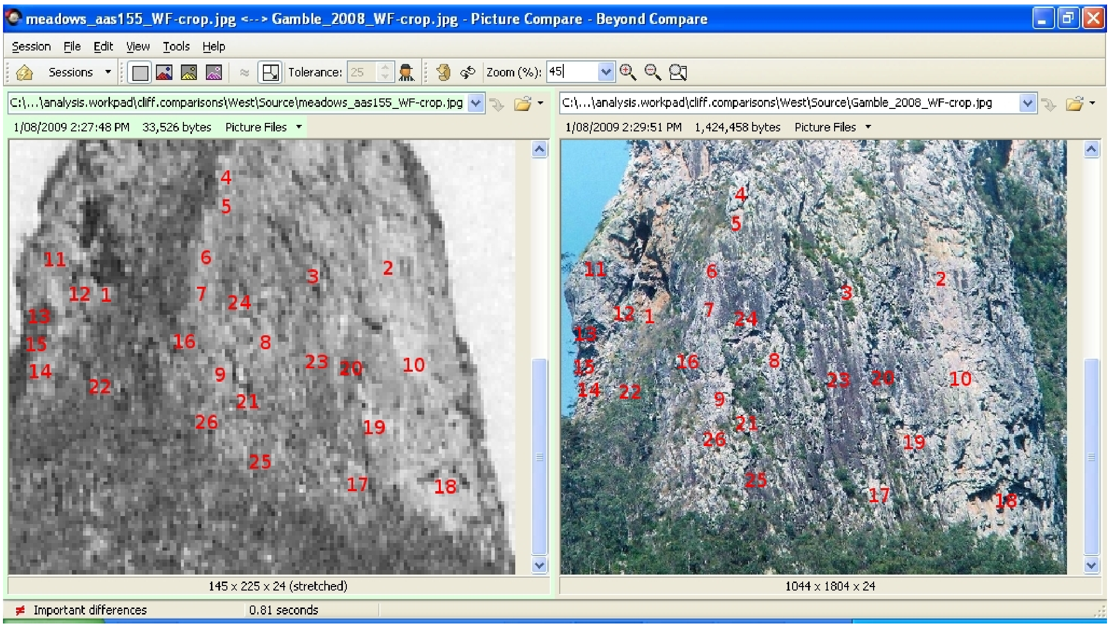

Figure 9. West Face Base - Matched Features - 1929-2008 (first image from Mike Meadows' collection)

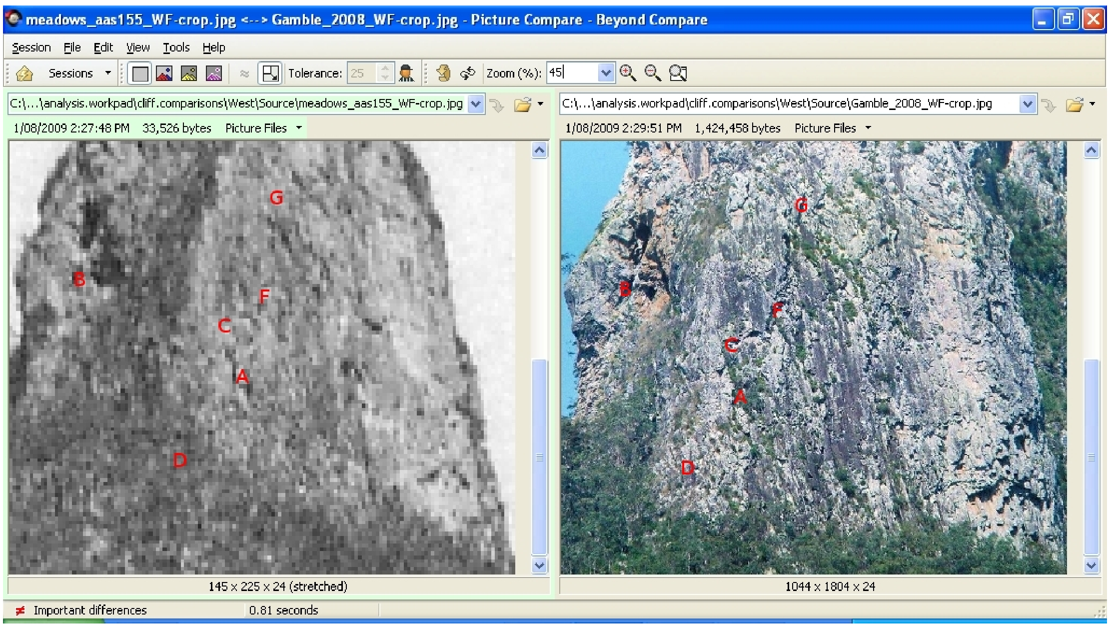

Figure 10. West Face Base - Unmatched Features - 1929-2008 (first image from Mike Meadows' collection)

Figure 9 shows the specific rock shapes identified as matching, validating that the feature and any underpinning rock surface has not changed over the last 80 years.

Figure 10 shows the specific visual anomalies that were found in this section of the West face during the examination that may indicate the presence of a rock fall site that occurred sometime during the last 80 years.

The mismatches at B, F and G are noted in the section above. C and A are possibly a continuation of the line of weakness of F and G. The area at D seems to be completely deforested now, which lacks explanation.

10.1.1.5 North Face – Overall Profile – 1929-2008

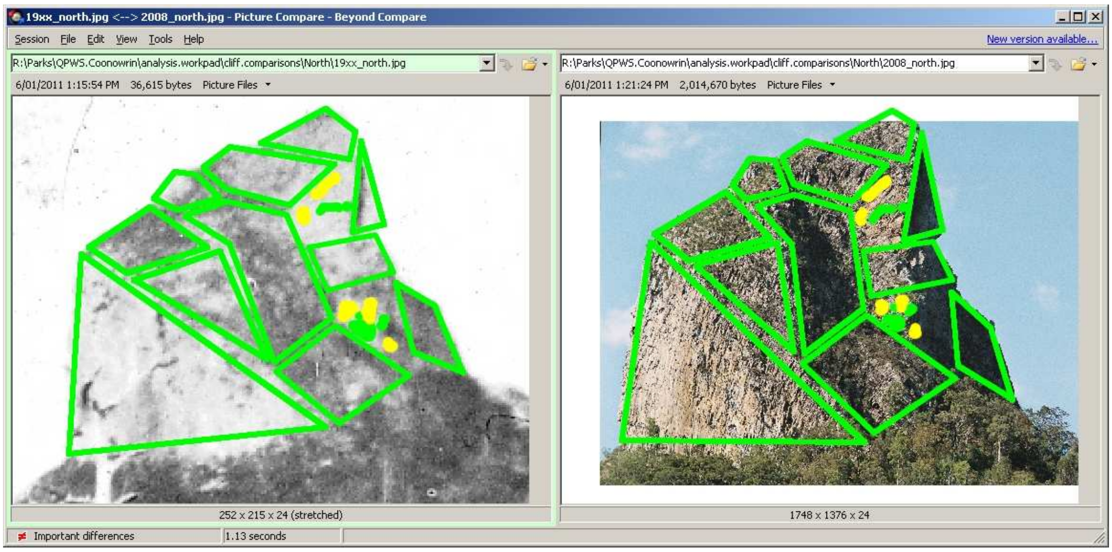

Figure 11. North Face - 1929-2008 (first image from Mike Meadows' collection)

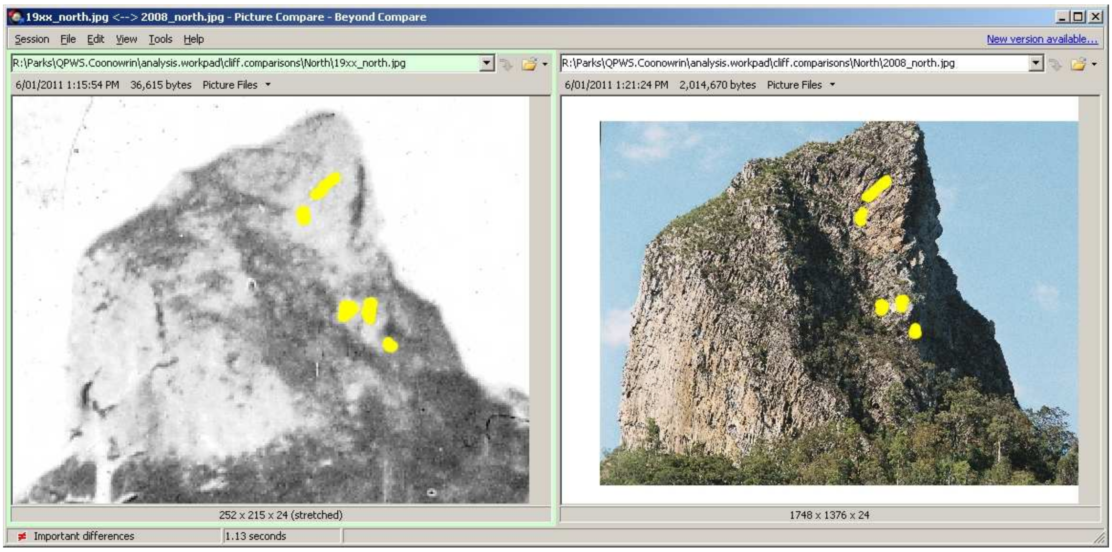

Figure 12. North Face - Unmatched Features - 1929-2008 (first image from Mike Meadows' collection)

Overall, Figure 11 and Figure 12 identify that over the past 80 years, there have been few if any major profile changes on the North face. The areas marked out in green indicate areas that were examined as closely as possible and found to have significant detail that indicate a match and therefore no rockfall identifiable, however there are some areas that are shown in yellow that had visual mismatches that could indicate rock fall points.

Of particular importance is the point of there being a close match found on the right side of the north face about ¾ of the way up. This is the area that was identified by Coffey (Coonowrin) 1999 [1] as “recent rock fall” as characterised by the “brown rock” areas. The implication is that this “brown rock” area does not appear to have suffered a rock fall in the last 80 years.

This was not examined in more detail as the photograph from 1929 is quite blurred and is very difficult to rely upon for more highly detailed comparisons.

10.1.1.6 East Face – Overall Profile – 1929-2008

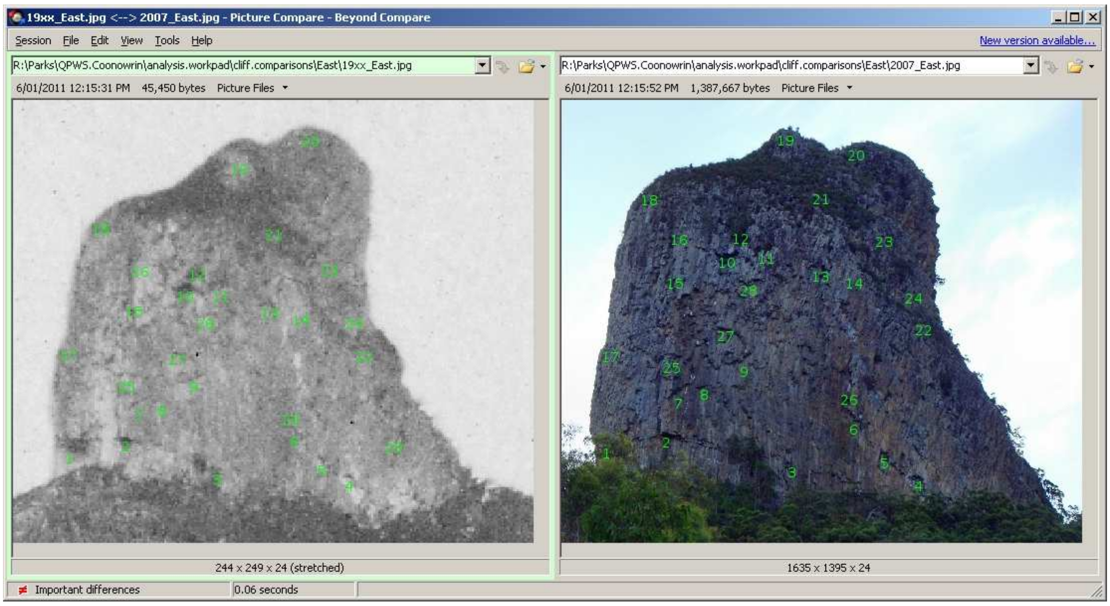

Figure 13. East Face - Matched Features - 1929-2008 (first image from Mike Meadows’ collection)

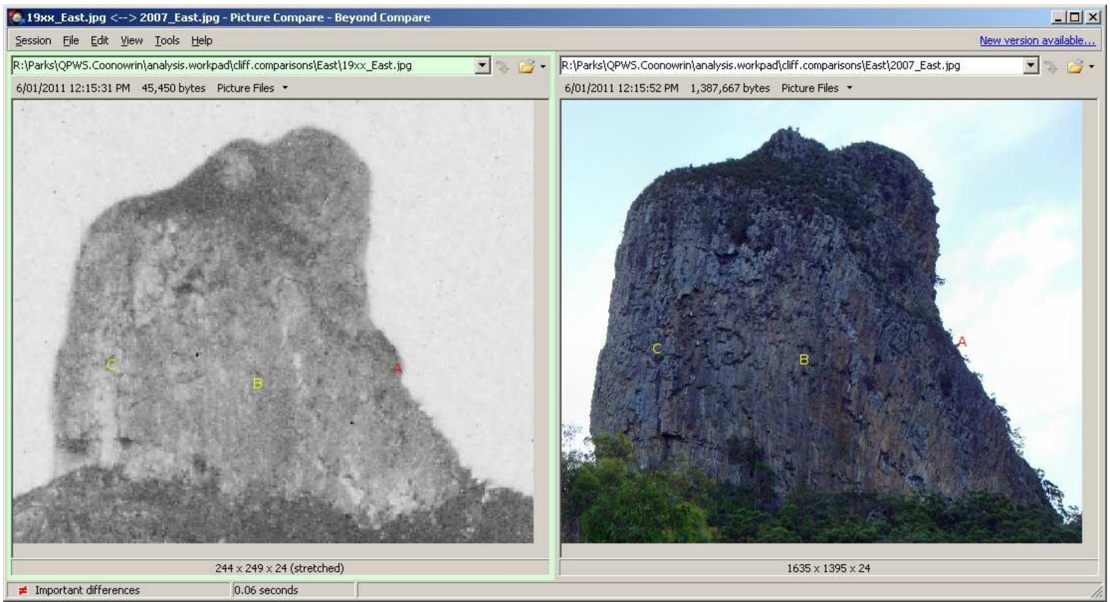

Figure 14. East Face - Unmatched Features - 1929-2008 (first image from Mike Meadows’ collection)

Overall, Figure 13 and Figure 14 identify that over the past 80 years, there have been few if any major profile changes on the East face. The annotations in Figure 13 indicate objects that were found to have significant detail that indicates a match and therefore no rockfall identifiable at that point and in the underpinning rock surface overall, however there are some areas that are shown on Figure 14 that had visual mismatches that could indicate rock fall points.

The point marked as “A” is more probably due to the mismatch in the photographer’s stance than a rock fall, however this could only be proven by revisiting the site and attempting to reproduce the original photographer’s stance.

The points at B and C seem to have had a significant enough change to indicate a possible fall site.

10.1.1.7 South Face – 1929-2008

No photographs were found of the South face from early times. They surely exist in many archives, but none were made available for the study.

10.1.1.8 Historic (80 year) Comparison Summary

Overall the North, West and East faces are unchanged over the 80 year period from 1929 to 2008. There are a few optical mismatches that may indicate some mid-scale rock fall on the north face, but this approximates to an amount within the expectations of the theoretical rockfall quantifications in *Establishing Natural Hazard Mechanisms and Quantities* above.

Of particular significance is the identification of matches in the details of the rock surface in areas marked in Coffey (Coonowrin) 1999 [1] as “recent rock fall”. This validates a theory that those surfaces have not suffered significant rock fall in the last 80 years at a minimum and therefore the recency of the rock fall must be interpreted as being a geological recency (hundreds to thousands of years, if not much more) rather than recency in a human time scale (years to decades).

10.1.2 Ten Year Contemporary Comparisons

These comparisons were made to establish whether there was evidence of coarse detail rockfall over the decade from 1999-2008, using photos displayed by Coffey in Coffey (Coonowrin) 1999 [1] as the start point and compared against photos taken ten years later during this study.

Many of the visual anomalies found during this analysis were found to be the consequence of shadows, different camera angles and vegetation growth, and so it is unlikely that every visual mismatch indicates a fallen rock site.

Even so, if it is presumed that a significant percentage of these are rock fall sites rather than shadows or vegetation growth, the resulting quantity of fall was estimated to still be comfortably within the expectations of the theoretical rockfall quantifications in *Establishing Natural Hazard Mechanisms and Quantities* above.

10.1.2.1 West Face Peak Detail – 1999-2008

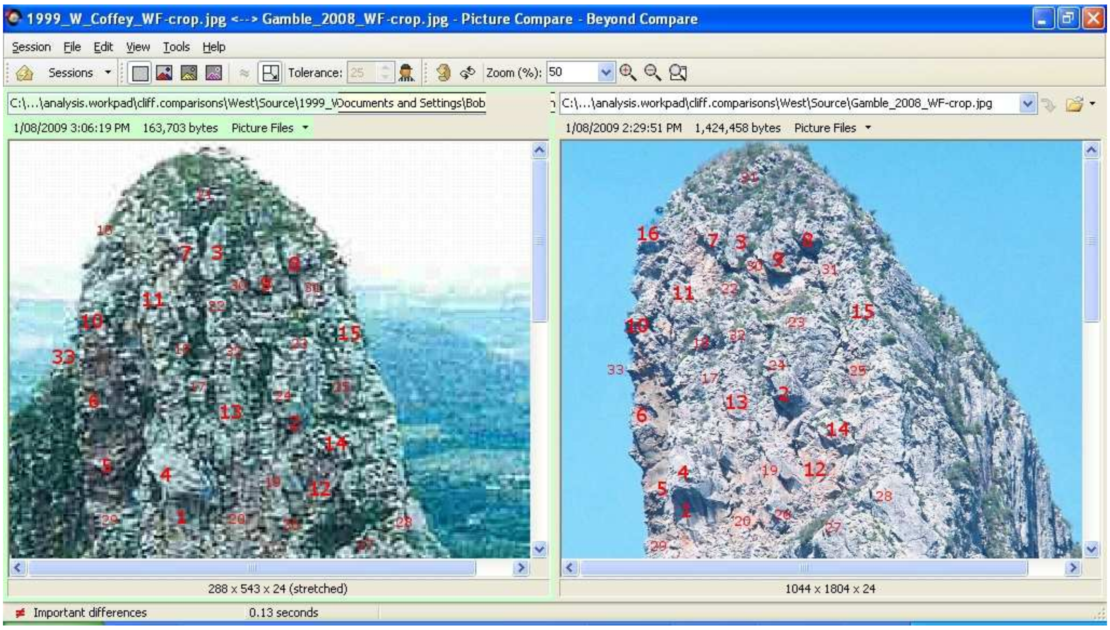

Figure 15. West Face Peak - Matched Features - 1999-2008 (first image from Coffey (Coonowrin) 1999 [1])

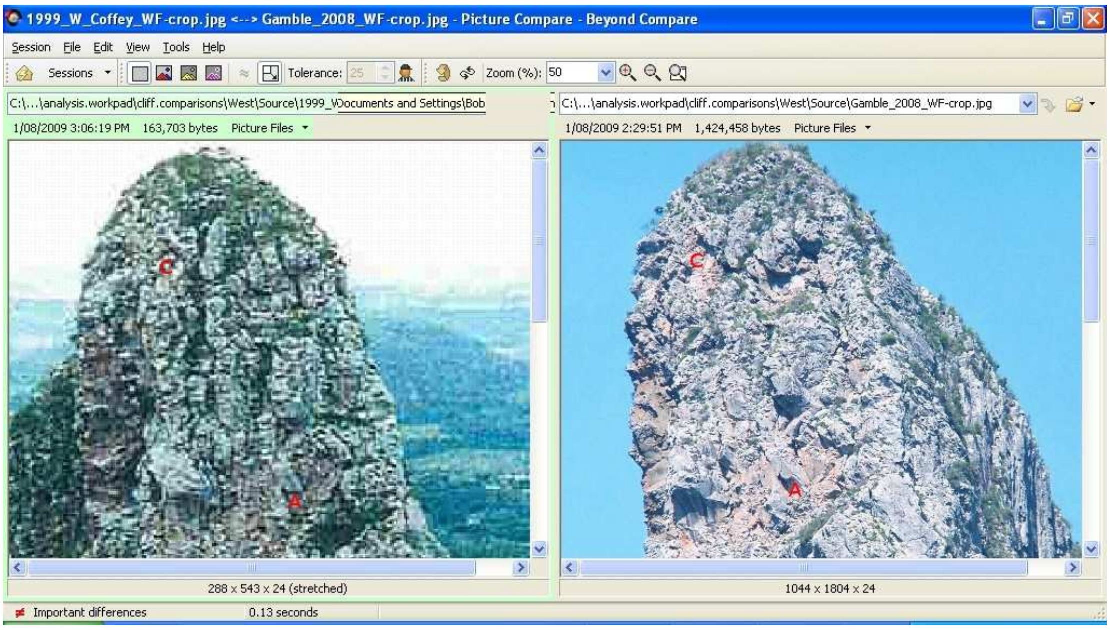

Figure 16. West Face Peak - Unmatched Features - 1999-2008 (first image from Coffey (Coonowrin) 1999 [1])

Overall, Figure 15, Figure 16, Figure 17, Figure 18 and Figure 19 identify that over the ten years from 1999 to 2008, there have been no major changes on the West face. The areas marked out in Figure 15, Figure 17 and Figure 19 indicate areas that were found to have significant detail that indicates a match and therefore no rockfall identifiable, however there are two areas that are shown in Figure 16 and Figure 18 that had visual mismatches that could indicate rock fall points.

Taking these to be fall sites, this is still estimated to fall within the theoretical expectations of naturally occurring rock fall frequency.

10.1.2.2 West Face Mid-Height Detail – 1999-2008

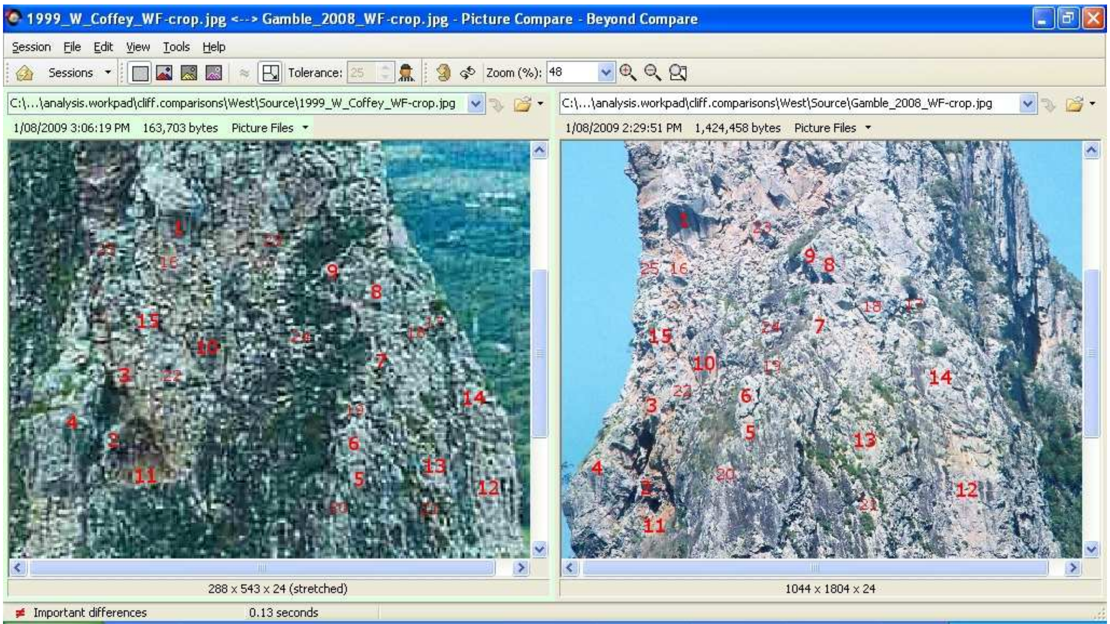

Figure 17. West Face Mid-height - Matched Features - 1999-2008 (first image from Coffey (Coonowrin) 1999 [1])

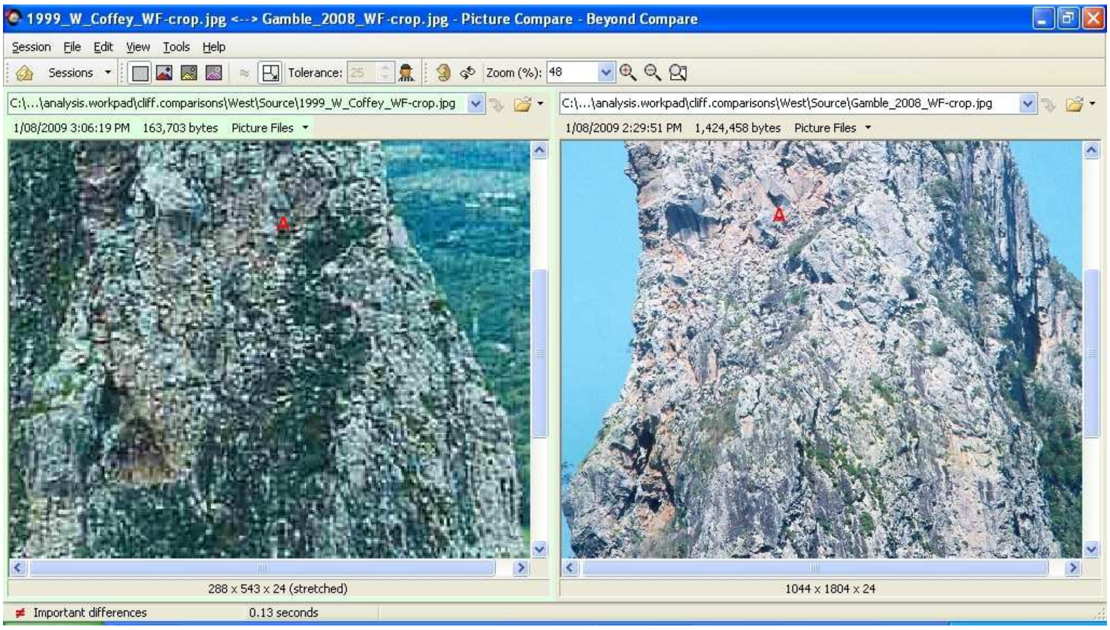

Figure 18. West Face Mid-height - Unmatched Features - 1999-2008 (first image from Coffey (Coonowrin) 1999 [1])

Point A is discussed in the section above.

10.1.2.3 West Face Base Detail – 1999-2008

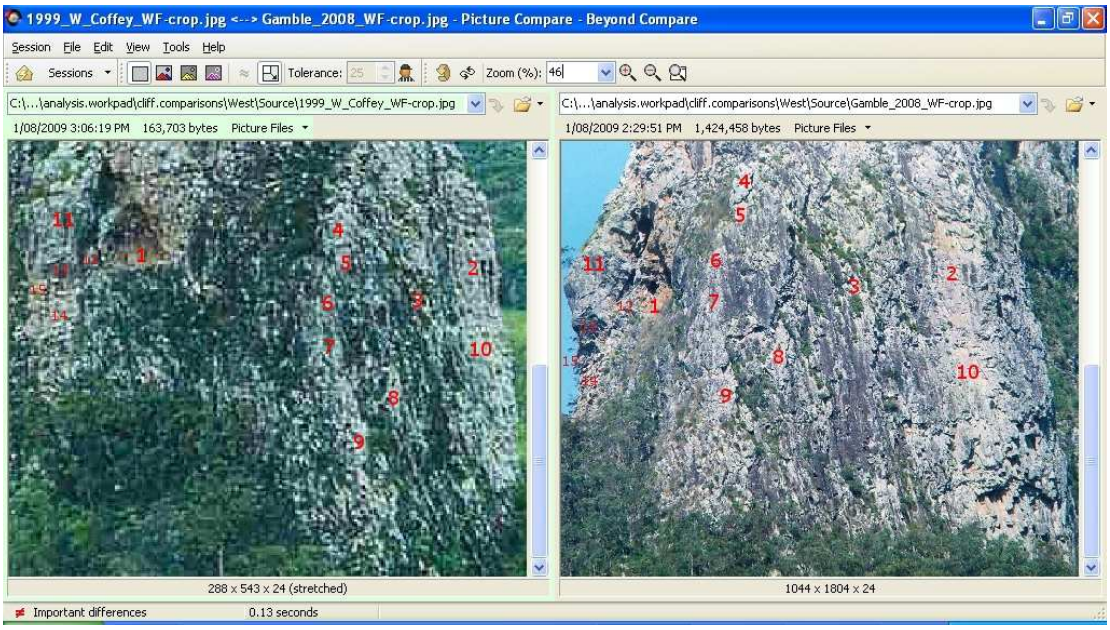

Figure 19. West Face Base - Matched Features - 1999-2008 (first image from Coffey (Coonowrin) 1999 [1])

I was not able to identify any specific loss of rock from this section of the face during this period from these photos.

10.1.2.4 North Face Overall – 1999-2008

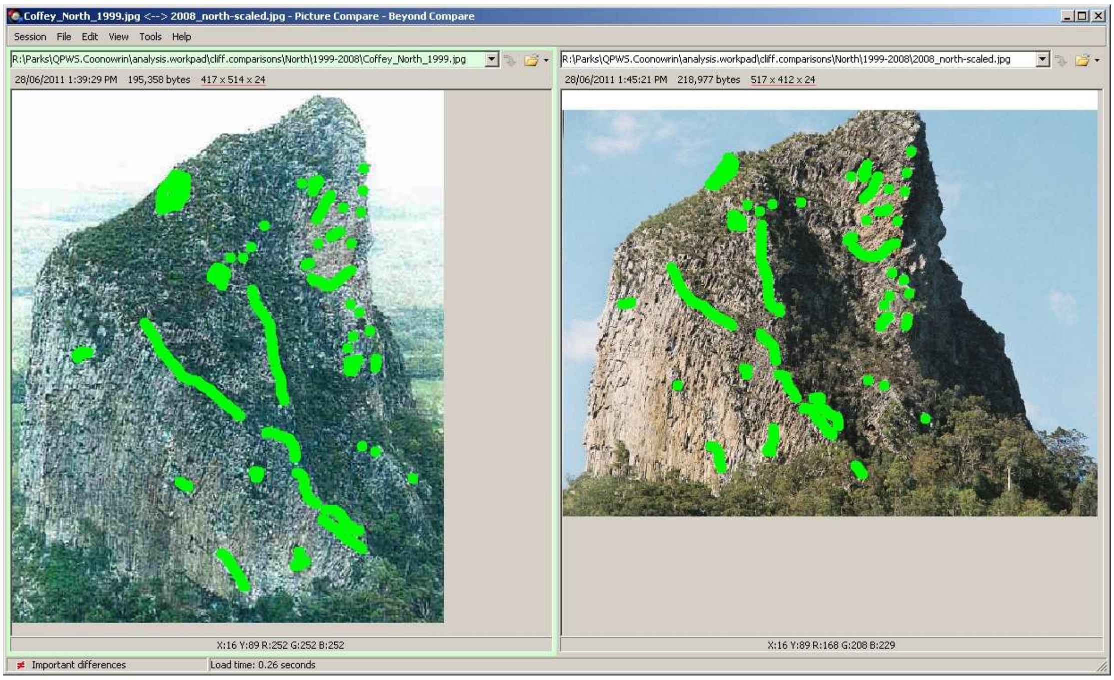

Figure 20. North Face - Matched Features - 1999-2008 (first image from Coffey (Coonowrin) 1999 [1])

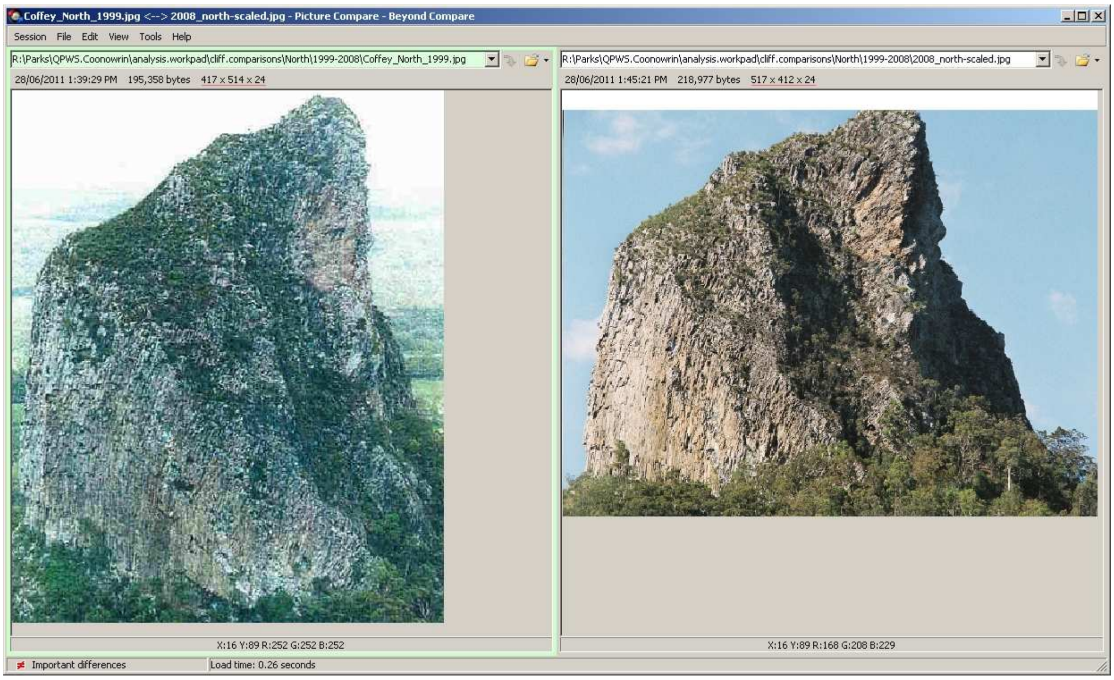

Figure 21. North Face - Unmatched Features - 1999-2008 (first image from Coffey (Coonowrin) 1999 [1])

I was not able to identify any specific loss of rock from this face during this period from these photos.

10.1.2.5 East Face– 1999-2008

There was no detailed photographic comparison performed for the East face for this period. It may be possible to find and compare photos for this period, but this is not captured in this report due to a lack of information to hand at the time of writing.

10.1.2.6 South Face Overall – 1999-2008

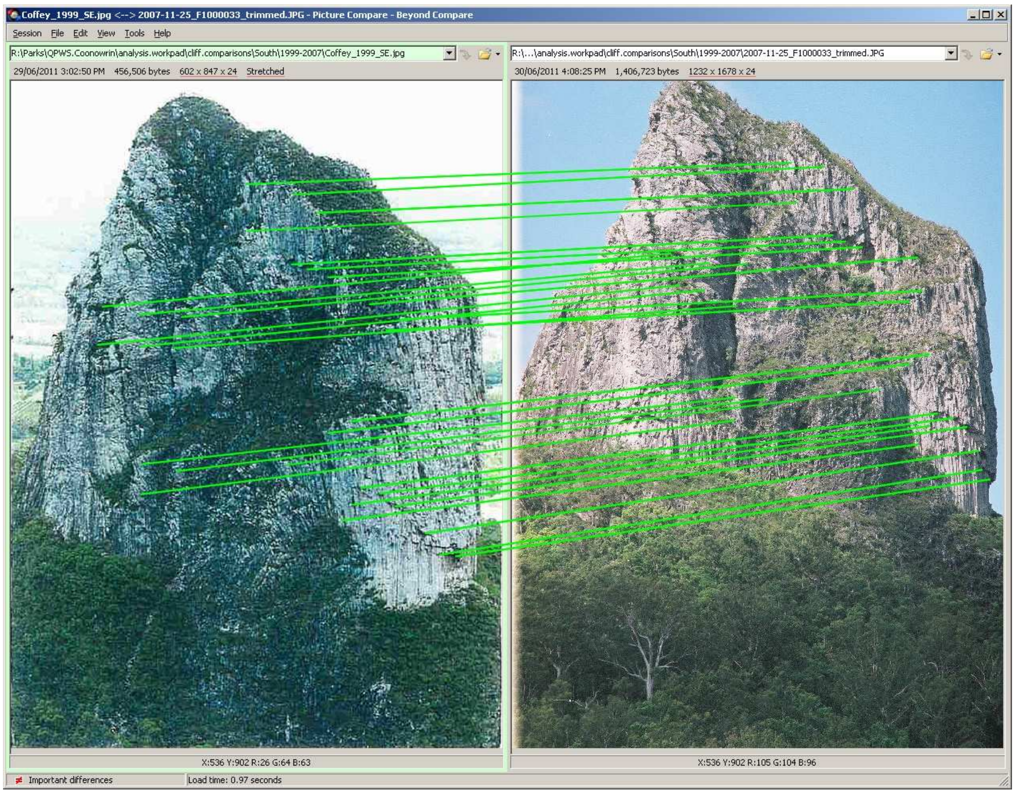

Figure 22. South Face - Matched Features - 1999-2008 (first image from Coffey (Coonowrin) 1999 [1])

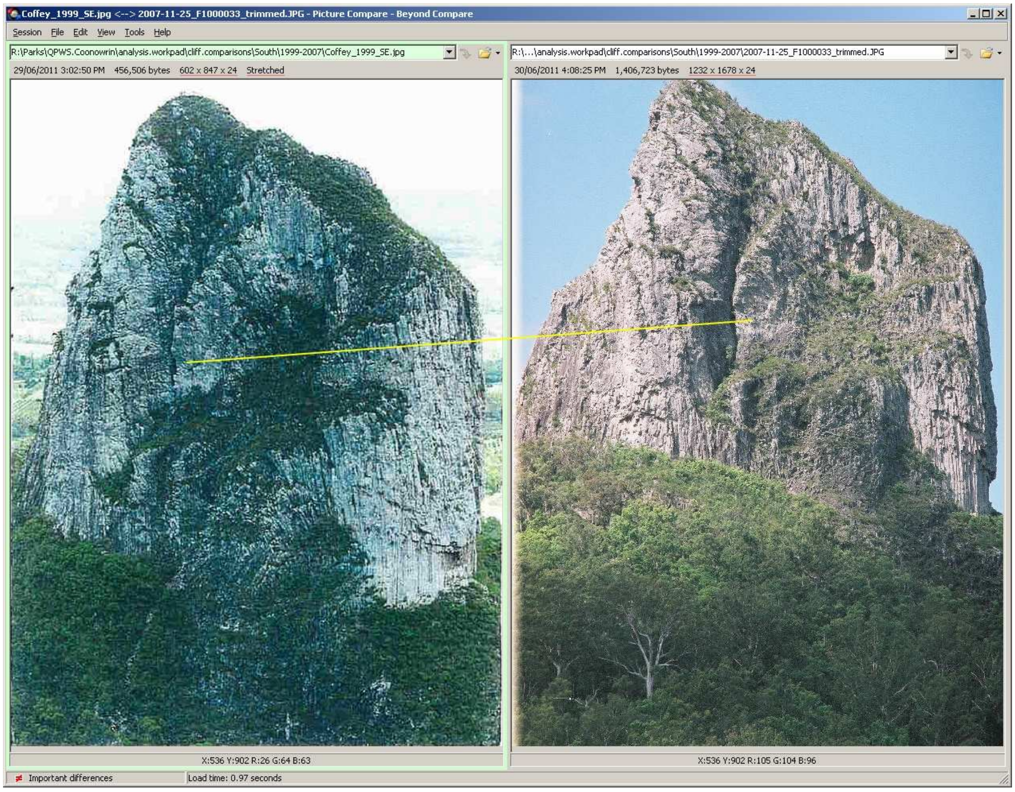

Figure 23. South Face - Unmatched Features - 1999-2008 (first image from Coffey (Coonowrin) 1999 [1])

Close examination of these photographs resulted in identification of only one suspected mismatch. Presuming this is a fall site, this still falls below the theoretical expectations of naturally occurring rock fall frequency.

10.1.2.7 South Face High Caves Detail – 1999-2008

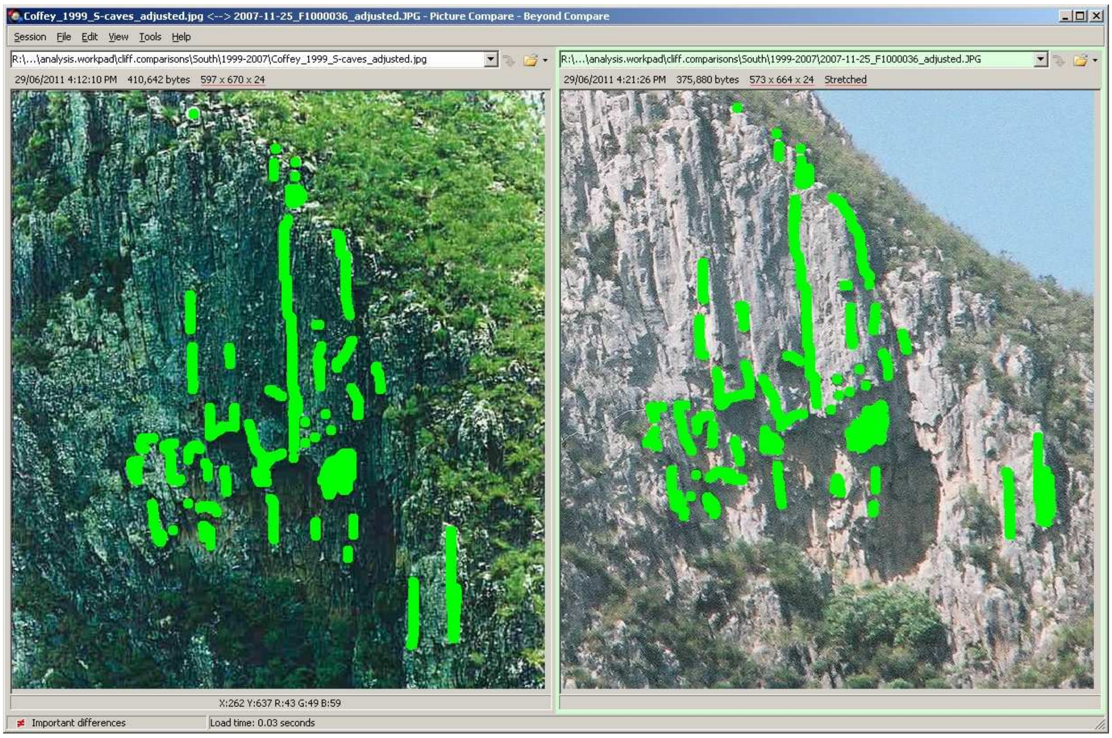

Figure 24. South Face Caves - Matched Features - 1999-2008 (first image from Coffey (Coonowrin) 1999 [1])

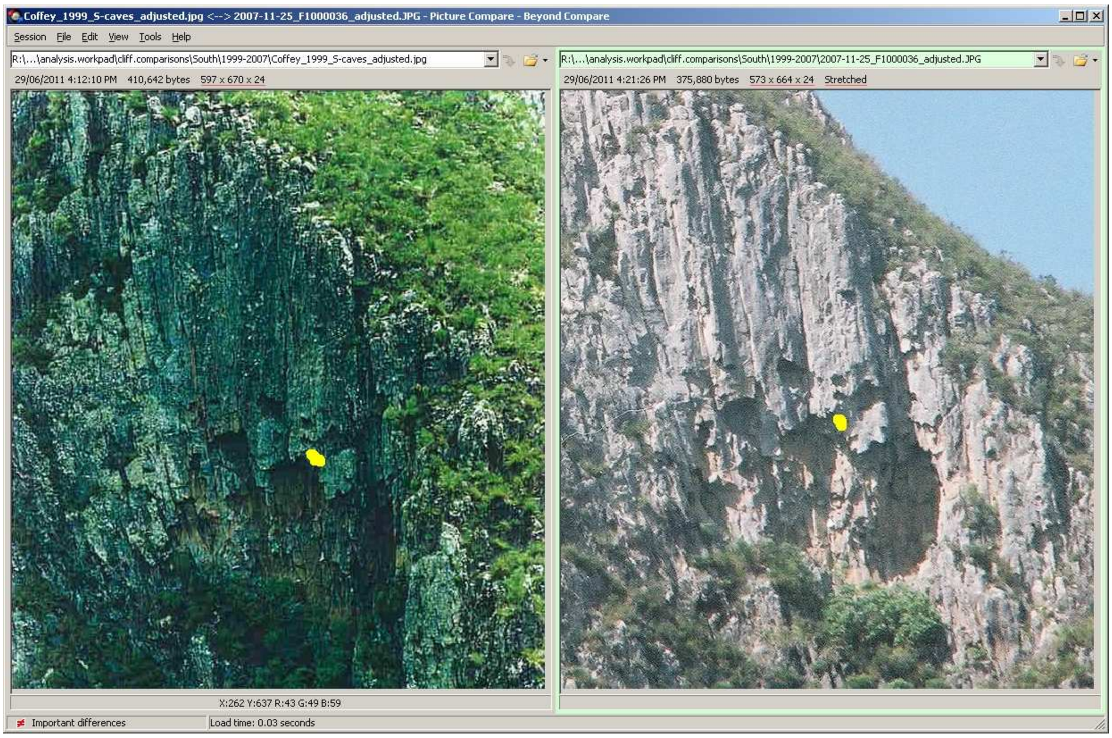

Figure 25. South Face Caves - Unmatched Features - 1999-2008 (first image from Coffey (Coonowrin) 1999 [1])

This comparison (Figure 24) indicated a high degree of matches in the area of the South face caves, which is an area marked by Coffey (Coonowrin) 1999 [1] as “very high risk”. There was one visual mismatch found as shown in Figure 25 and Figure

26, and it is possible that this may be a fallen rock. This also falls within the theoretical expectations of naturally occurring rock fall frequency.

Figure 26. Detail of the anomaly in the South cave (first image from Coffey (Coonowrin) 1999 [1])

10.1.2.8 Ten Year Contemporary Comparison Summary

Overall all faces are mostly unchanged over the ten year period from 1999 to 2008. There are a few optical mismatches that may indicate some small-scale rock fall on the West, and South faces, but this approximates to an amount well within the expectations of the theoretical rockfall quantifications in *Establishing Natural Hazard Mechanisms and Quantities* above.

Of particular significance is the identification of matches in the details of the rock surface ten years later in areas marked in Coffey (Coonowrin) 1999 [1] as “very high risk”. This validates a theory that those surfaces have not suffered significant rock fall in the 10 years since Coffey (Coonowrin) 1999 [1], and therefore designation of those areas of the rock surface as “very high risk” does not extend to forming expectations that there will be a high frequency of rock fall from those faces during a typical ten year timeframe.

10.1.3 One Year Contemporary Comparisons

These comparisons were made to establish whether there was evidence of fine detail rockfall over the year from 2007-2008, using near-identical photos taken a year apart during the study.

A fine detail examination of the West and South faces disclosed a number of visual differences between the 2007 and 2008 photographs of these faces, as indicated in *West Face Overall* – 2007-2008 and *South Face – 2007-2008* below.

As was found by direct examination on site of the rock surfaces, a number of these were found to be the consequence of shadow effects due principally to slightly different photography times. Of particular example, the upper anomaly shown in object 14 on the West face (Figure 41) was thought for a moment to be the shape of a person hanging upside down in the North cave, and the image was referred to the local police office for examination at the time. They confirmed that the shape was in fact nothing more than a rock surface affected by shadows, and this was examined in person later.

To give as much credence as it seemed judicious to the theory that rock does fall off the cliff surface, the faces were examined and estimates made as to the probability that each visual anomaly is the consequence of a rock fall incident. This was used to calculate a gross frequency and volume of rock fall during the period.

10.1.3.1 West Face Overall – 2007-2008

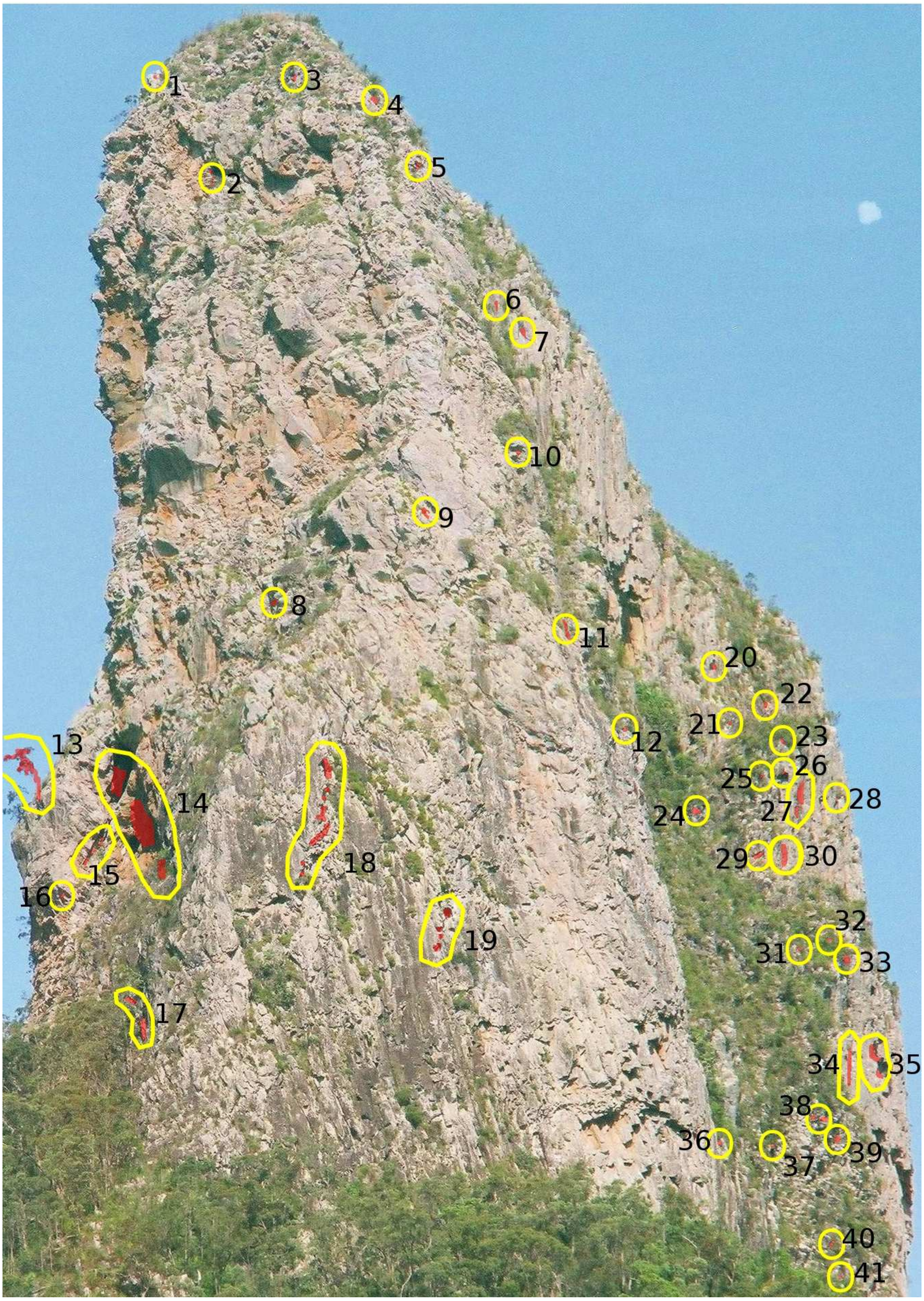

Figure 27. West face visual anomalies - 2007-2008 (photographs in this section taken by Mark Gamble)

Object #	Speculative Explanation (for estimation purposes)	Est % likelihood as Rockfall	Object size (pixels)	Est depth (pixels)	Object area m2	Est object volume m3	Vol in cu-ft	Probability adjusted fall volume (m3)
1	Vegetation/Shadow/Rockfall	20%	22	4	0.180	0.065	2.3	0.013
2	Vegetation/Rockfall	20%	62	4	0.507	0.183	6.5	0.037
3	Vegetation/Shadow	5%	49	5	0.401	0.181	6.4	0.009
4	Shadow	5%	76	8	0.621	0.450	15.9	0.022
5	Vegetation/Shadow	5%	49	3	0.401	0.109	3.8	0.005
6	Shadow/Vegetation	5%	51	3	0.417	0.113	4.0	0.006
7	Vegetation/Shadow/Rockfall	20%	76	7	0.621	0.393	13.9	0.079
8	Vegetation removed	1%	69	7	0.564	0.357	12.6	0.004
9	Vegetation	1%	98	5	0.801	0.362	12.8	0.004
10	Rockfall/Shadow/Vegetation	50%	36	6	0.294	0.160	5.6	0.080
11	Shadow/Vegetation	1%	146	4	1.194	0.432	15.2	0.004
12	Rockfall	50%	37	5	0.303	0.137	4.8	0.068
13	Tree has fallen off	0%	0	0	0.000	0.000	0.0	0.000
14	Confirmed Shadow. Personally examined.	0%	2338	18	19.117	31.116	1098.9	0.000
15	Rockfall along the Coffey's block slip plane	80%	91	2	0.744	0.135	4.8	0.108
16	Shadow	5%	31	3	0.253	0.069	2.4	0.003
17	Vegetation masking rock formation	5%	285	6	2.330	1.264	44.7	0.063
18	Shadow	1%	1040	8	8.504	6.152	217.2	0.062
19	Shadow	1%	345	8	2.821	2.041	72.1	0.020
20	Shadow/Rockfall	20%	43	6	0.352	0.191	6.7	0.038
21	Vegetation	20%	26	5	0.213	0.096	3.4	0.019
22	Vegetation	20%	40	5	0.327	0.148	5.2	0.030
23	Vegetation	5%	38	4	0.311	0.112	4.0	0.006
24	Vegetation	5%	100	9	0.818	0.665	23.5	0.033
25	Vegetation	20%	23	4	0.188	0.068	2.4	0.014
26	Vegetation/Shadow/Rockfall	20%	19	4	0.155	0.056	2.0	0.011
27	Shadow	5%	325	8	2.657	1.922	67.9	0.096
28	Vegetation/Shadow/Rockfall	20%	9	3	0.074	0.020	0.7	0.004
29	Vegetation/Shadow	5%	75	5	0.613	0.277	9.8	0.014
30	Vegetation/Shadow	5%	240	8	1.962	1.420	50.1	0.071
31	Vegetation/Shadow	5%	27	5	0.221	0.100	3.5	0.005
32	Vegetation	5%	32	4	0.262	0.095	3.3	0.005
33	Rockfall/Vegetation	50%	101	9	0.826	0.672	23.7	0.336
34	Shadow	1%	280	5	2.289	1.035	36.6	0.010
35	Shadow	5%	318	8	2.600	1.881	66.4	0.094
36	Rockfall/Vegetation	50%	36	6	0.294	0.160	5.6	0.080
37	Rockfall/Vegetation	50%	22	4	0.180	0.065	2.3	0.033
38	Vegetation/Shadow	5%	104	7	0.850	0.538	19.0	0.027
39	Rockfall	50%	71	7	0.581	0.367	13.0	0.184
40	Vegetation/Shadow	5%	41	3	0.335	0.091	3.2	0.005
41	Vegetation	20%	23	4	0.188	0.068	2.4	0.014
	Est no of events:	6.7		Estimated rockfall on W face in 2007-2008:				1.714 m3
	Average fall size:	0.257 m3						
	Pixel size (m):	0.0904255						

Table 16. Summary of mismatched objects – West face – 2007-2008

Using the sum of the individual probabilities that each of these image anomalies is a rock fall incident, it is predicted to be most probable that there were 6 to 7 incidents of significant rock fall averaging $0.26m^3$ each off this face, totalling a volume of $1.72\ m^3$ during the year. Given the vagaries of this method of analysis and the breadth of interpretation possible, this still fits well at a broad statistical level with the Coffey (Coonowrin) 1999 [1] prediction that there would be an average rockfall of 3 to 4 falls per year each of $0.5m^3$, totalling $1.5m^3$ per year, and those predicted rock frequencies seem to be upheld by this observation.

10.1.3.2 West Face – 2007-2008 – Detailed Possible Rockfall Sites

The following are the records of examination used to determine the probability that each is a site of rock fall. This is still only an approximate probability and each may be caused by other visual effects, however a "best and fairest" estimate was made for engineering risk analysis purposes.

Each figure has table cells showing the speculative explanation (for estimation purposes) and the estimated % likelihood that the anomaly is in fact rockfall.

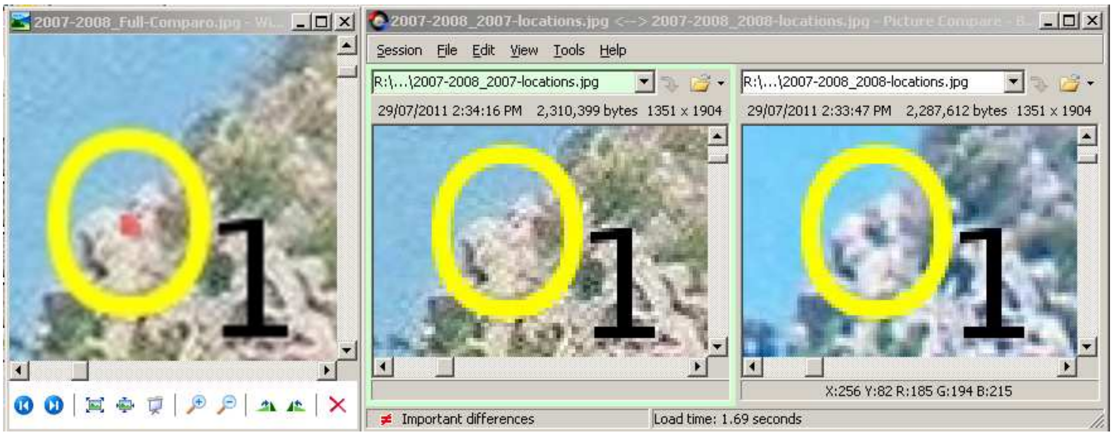

Figure 28. Detail comparison on West face

Vegetation/Shadow/Rockfall	20%

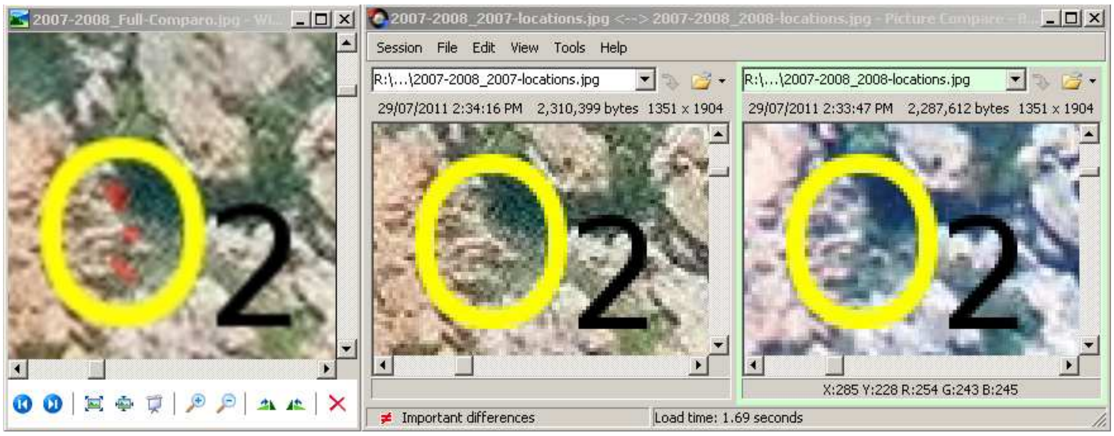

Figure 29. Detail comparison on West face

Vegetation/Rockfall	20%

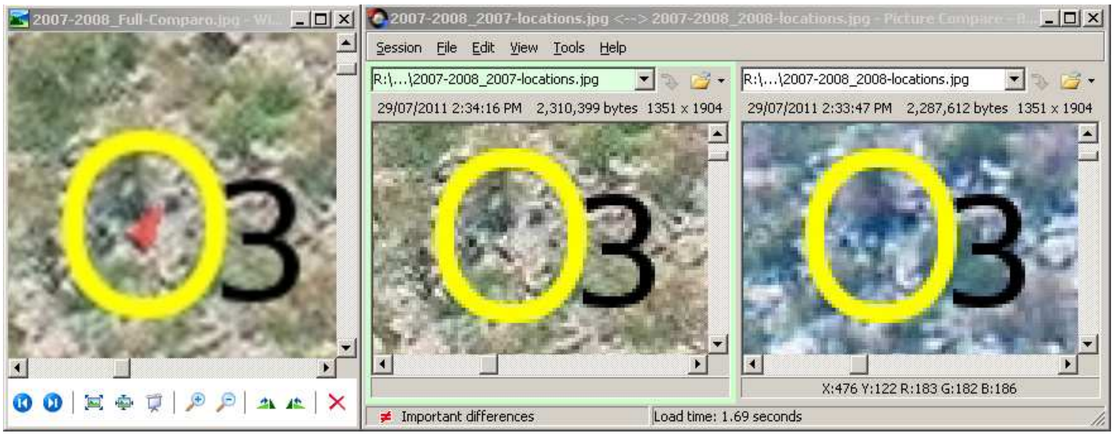

Figure 30. Detail comparison on West face

Vegetation/Shadow	5%

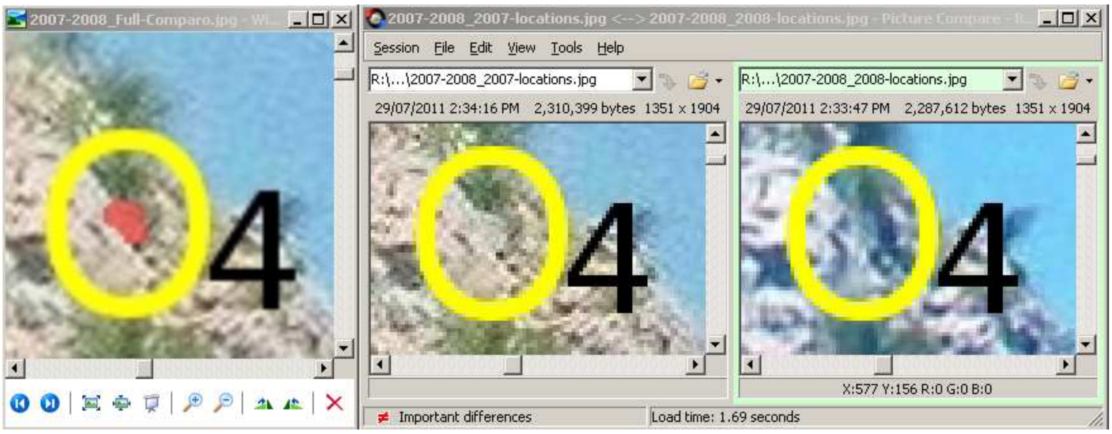

Figure 31. Detail comparison on West face

Shadow 5%

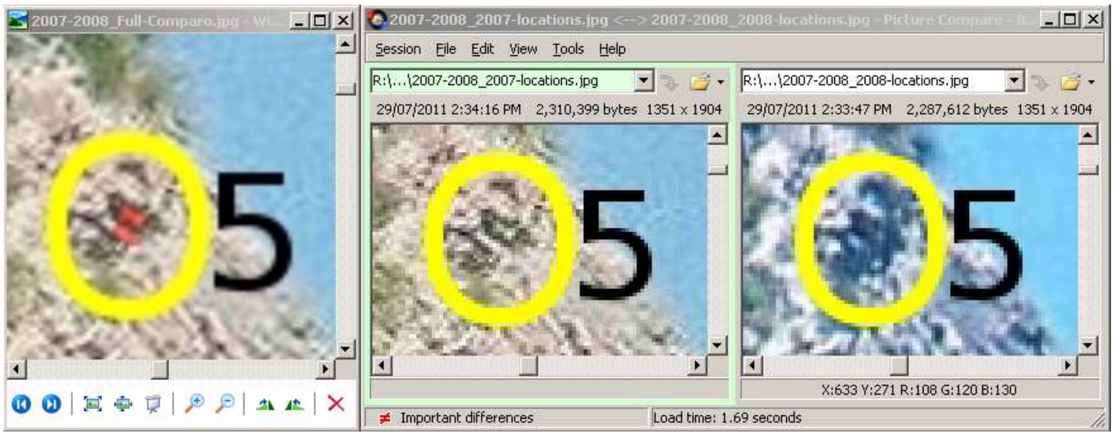

Figure 32. Detail comparison on West face

Vegetation/Shadow 5%

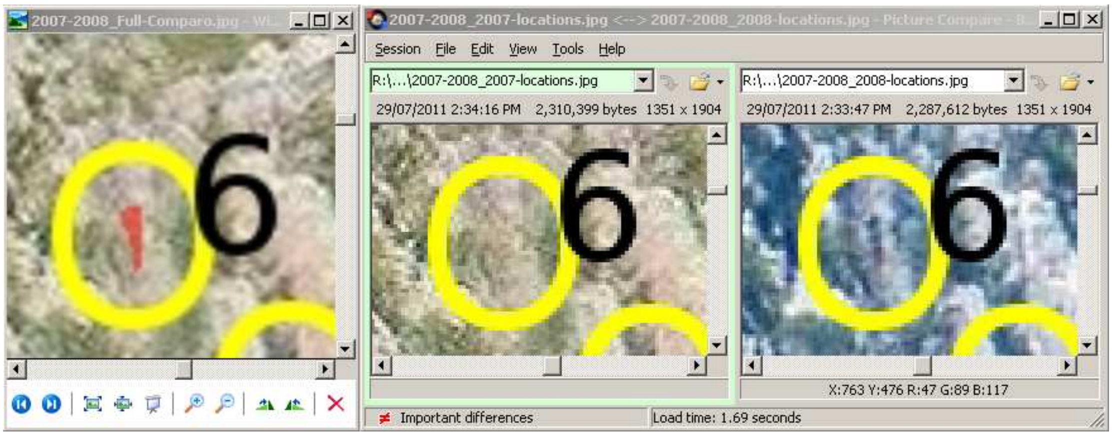

Figure 33. Detail comparison on West face

Shadow/Vegetation 5%

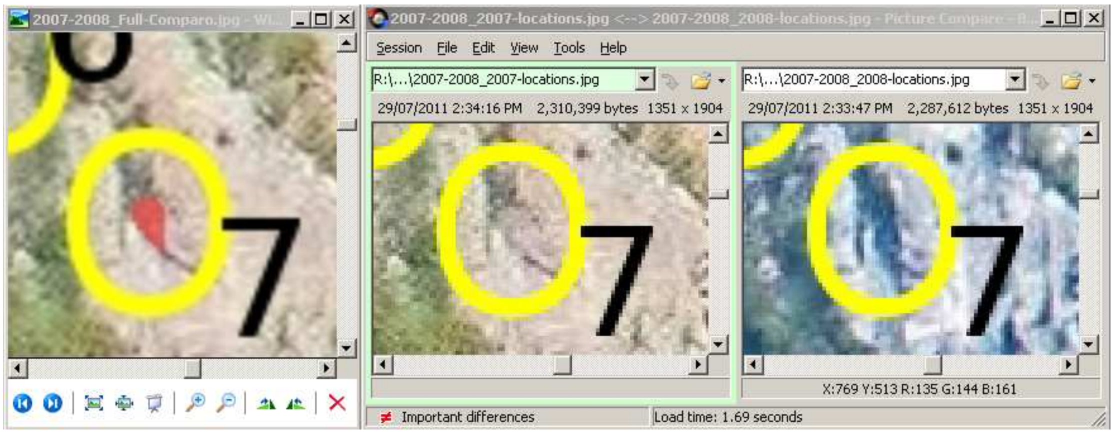

Figure 34. Detail comparison on West face

Vegetation/Shadow/Rockfall 20%

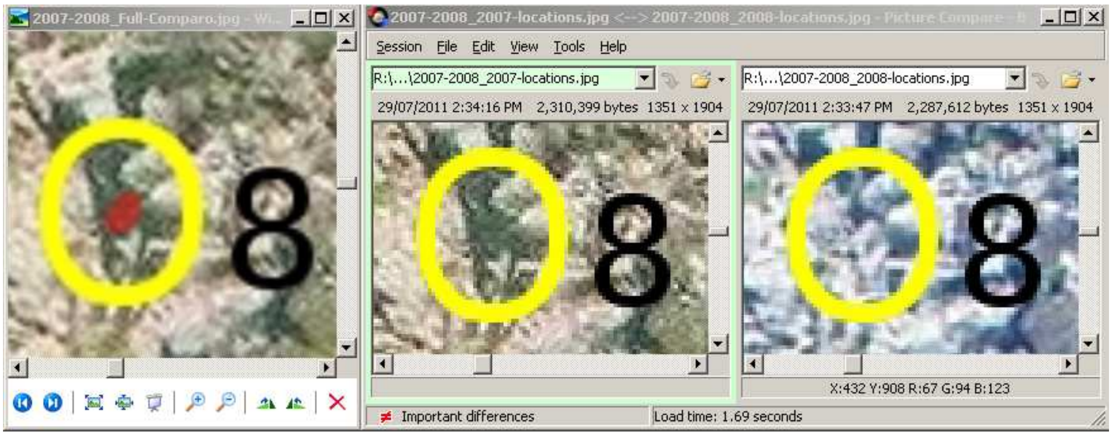

Figure 35. Detail comparison on West face

Vegetation removed 1%

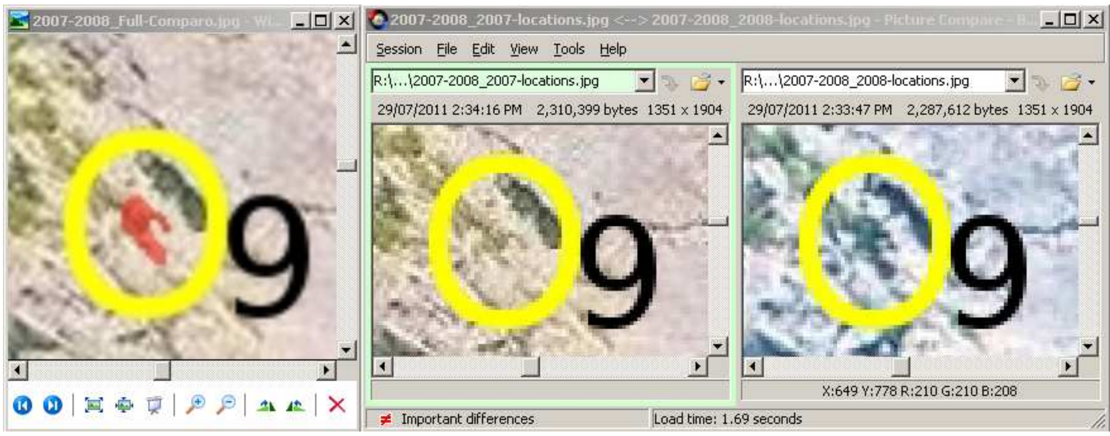

Figure 36. Detail comparison on West face

Vegetation 1%

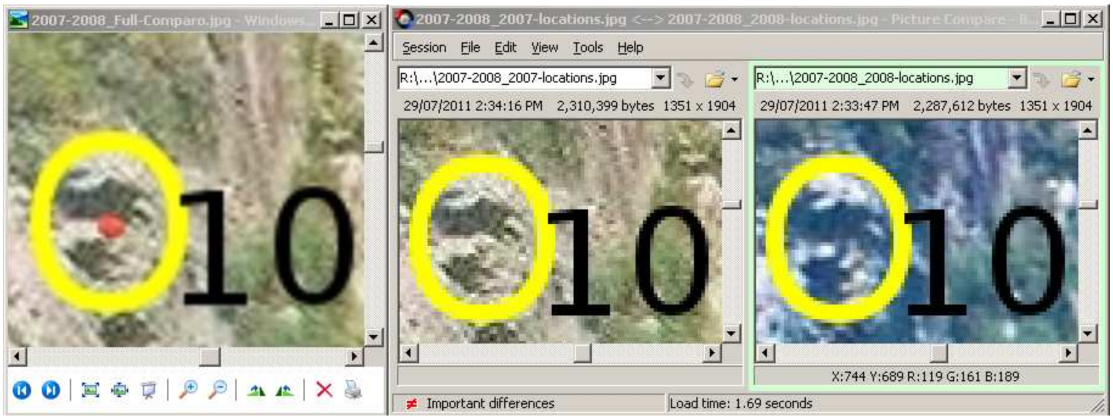

Figure 37. Detail comparison on West face

Rockfall/Shadow/Vegetation 50%

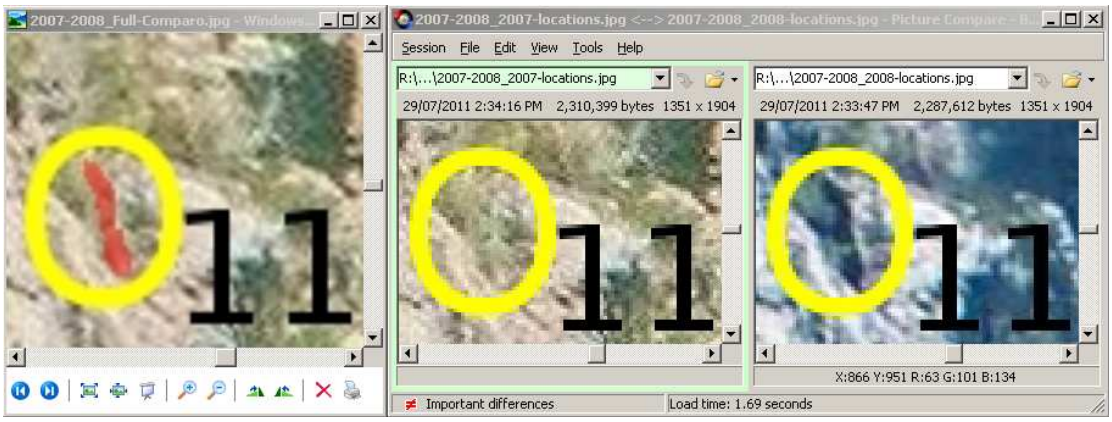

Figure 38. Detail comparison on West face

Shadow/Vegetation 1%

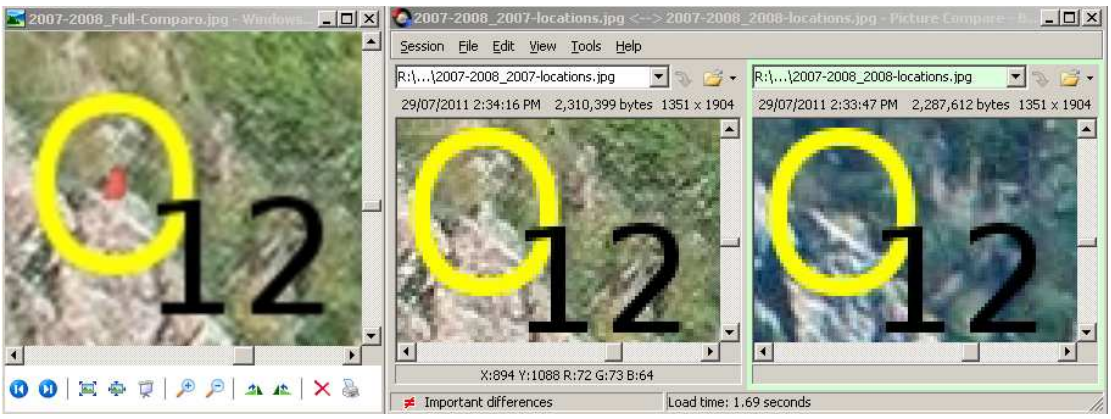

Figure 39. Detail comparison on West face

Rockfall 50%

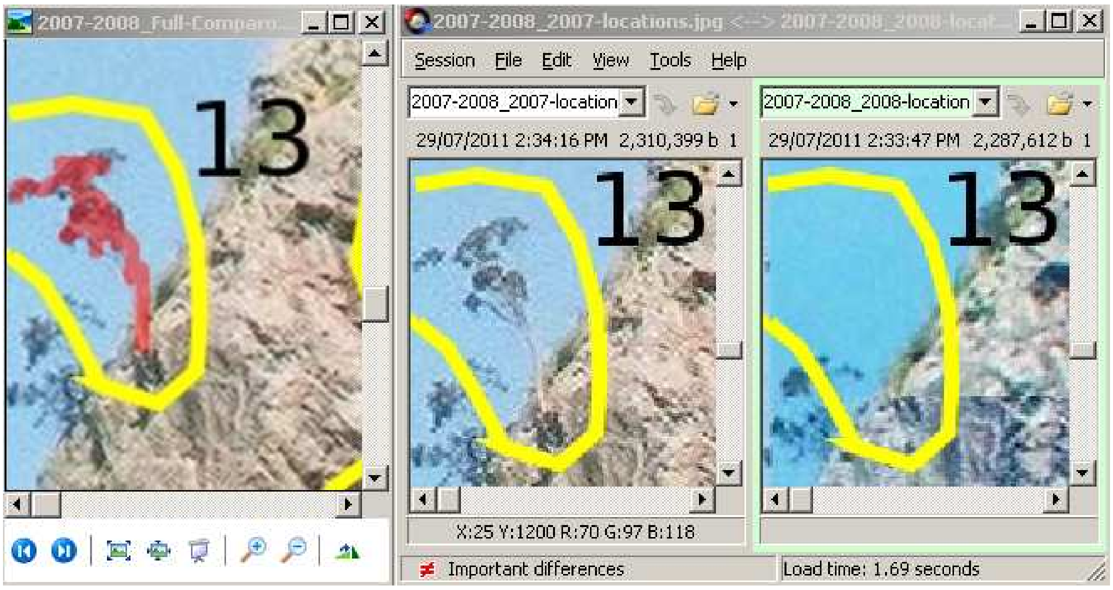

Figure 40. Detail comparison on West face

Tree has fallen off 0%

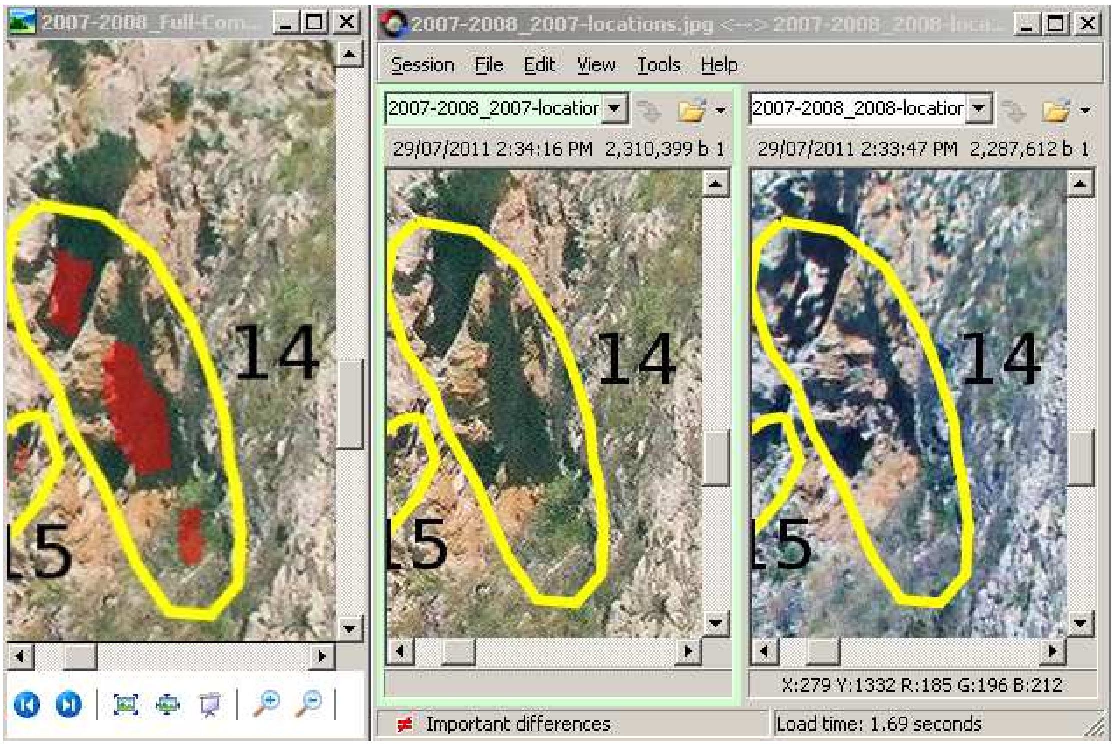

Figure 41. Detail comparison on West face

Confirmed Shadow. Personally examined. 0%

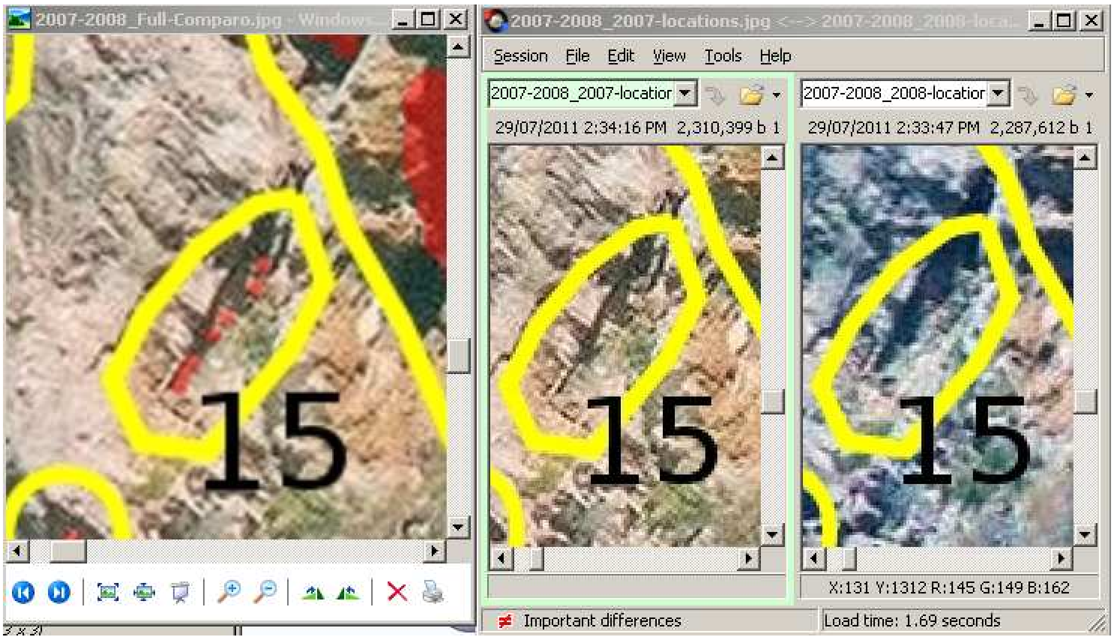

Figure 42. Detail comparison on West face

Rockfall along the Coffey's block slip plane 80%

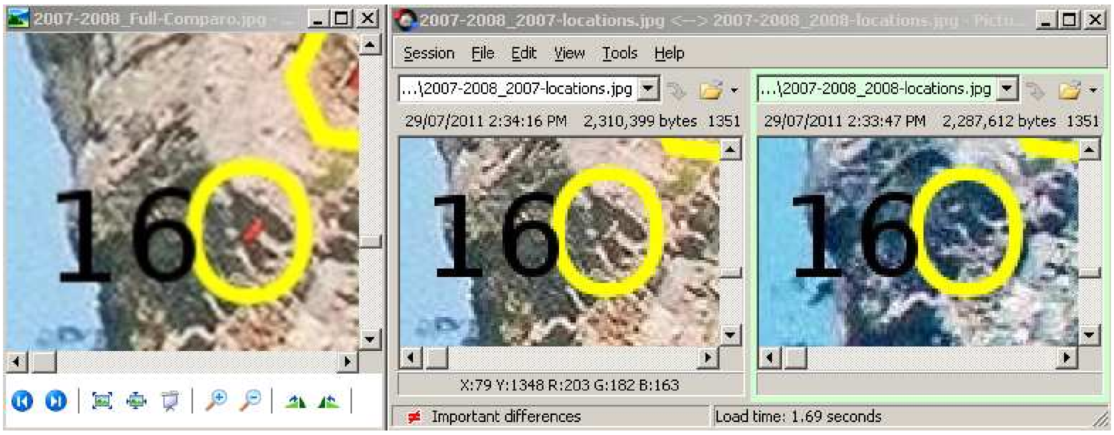

Figure 43. Detail comparison on West face

Shadow 5%

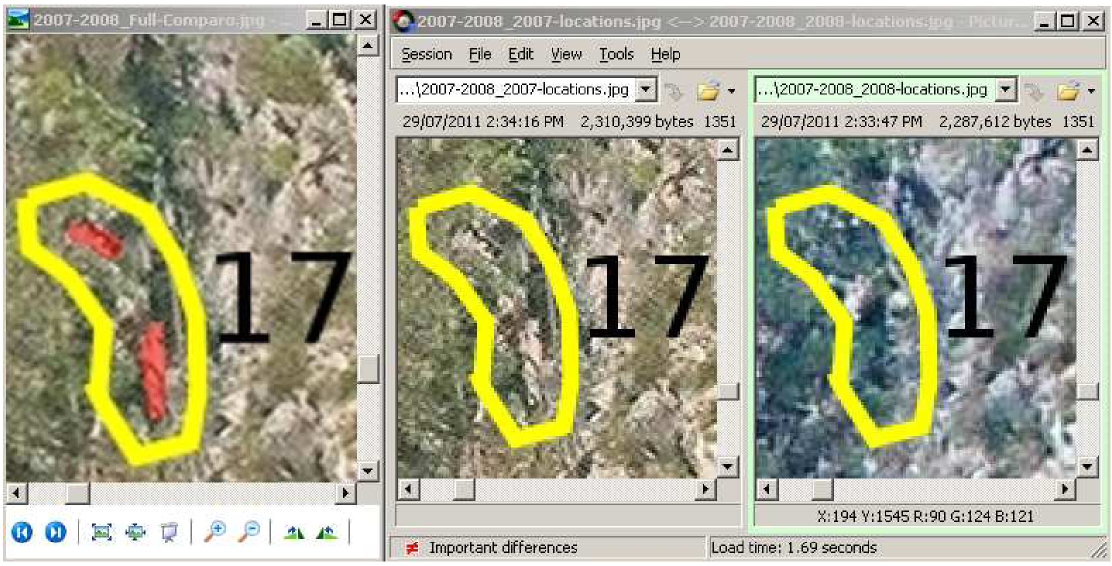

Figure 44. Detail comparison on West face

Vegetation masking rock formation 5%

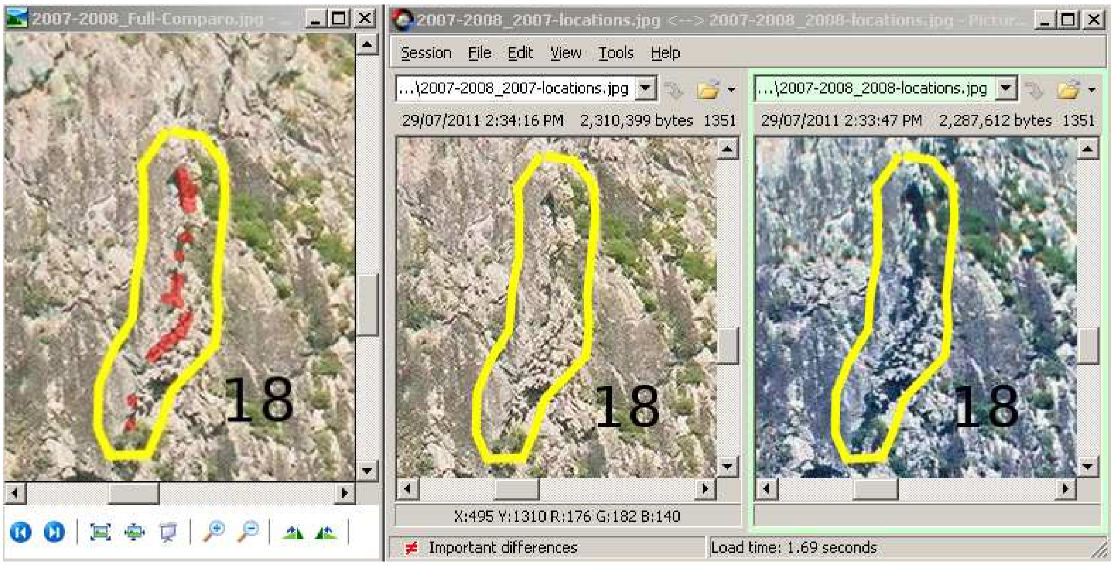

Figure 45. Detail comparison on West face

Shadow 1%

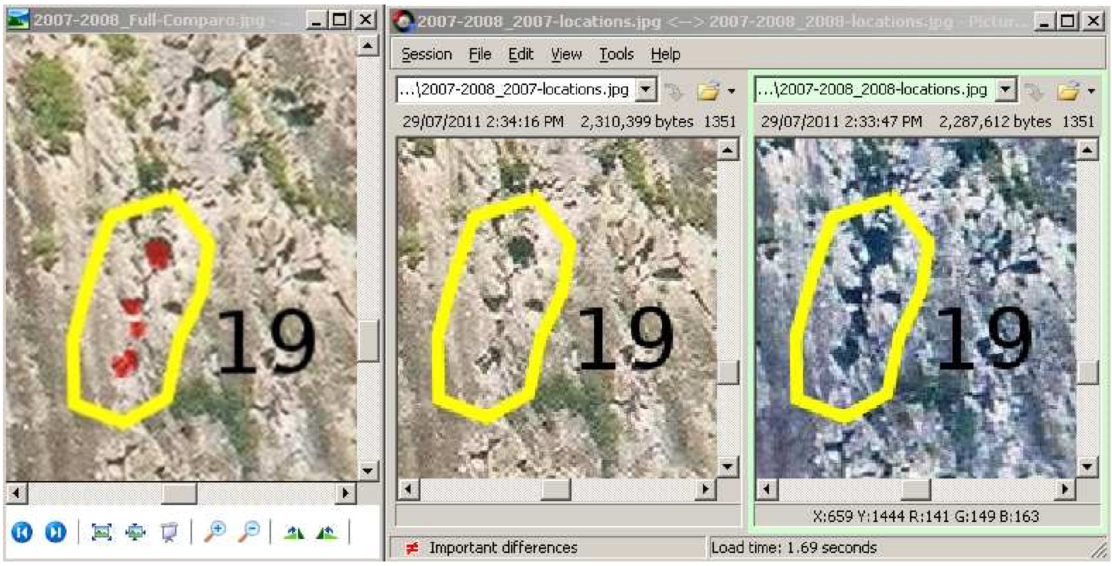

Figure 46. Detail comparison on West face

Shadow 1%

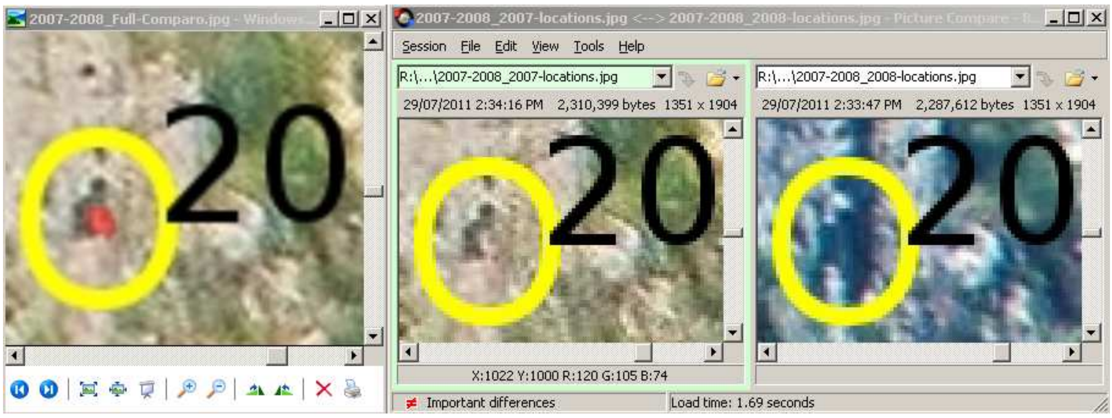

Figure 47. Detail comparison on West face

Shadow/Rockfall 20%

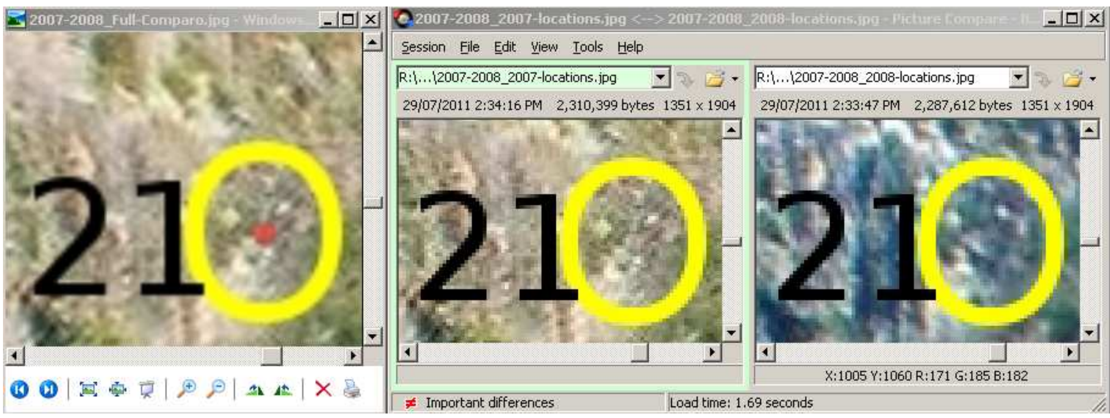

Figure 48. Detail comparison on South face, from West

Vegetation 20%

Figure 49. Detail comparison on South face, from West

Vegetation 20%

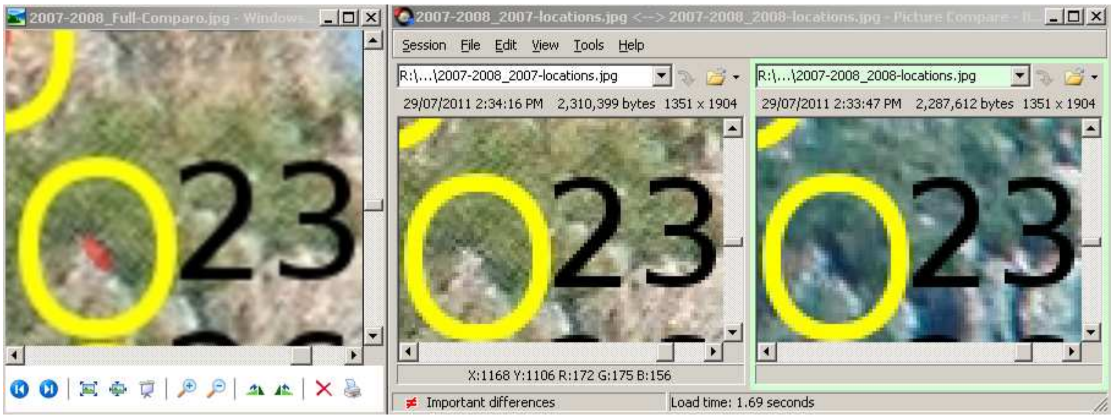

Figure 50. Detail comparison on South face, from West

Vegetation 5%

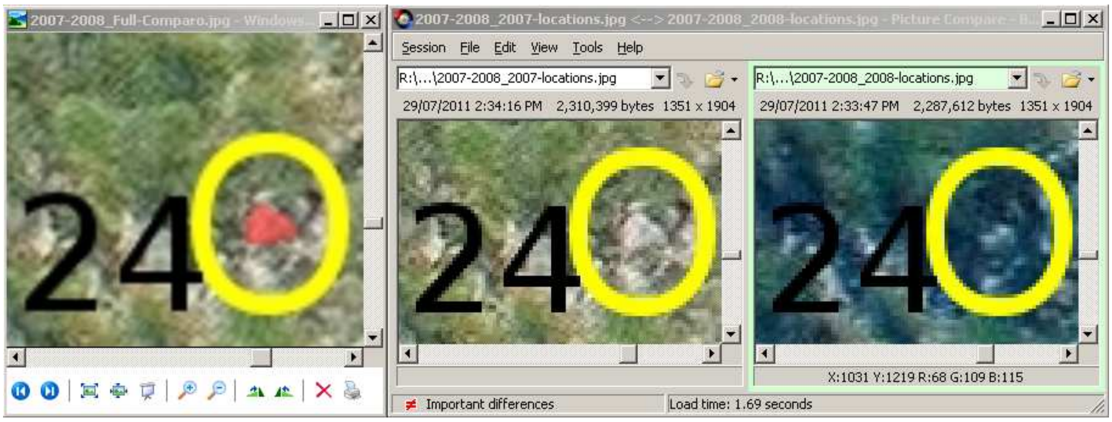

Figure 51. Detail comparison on South face, from West

Vegetation 5%

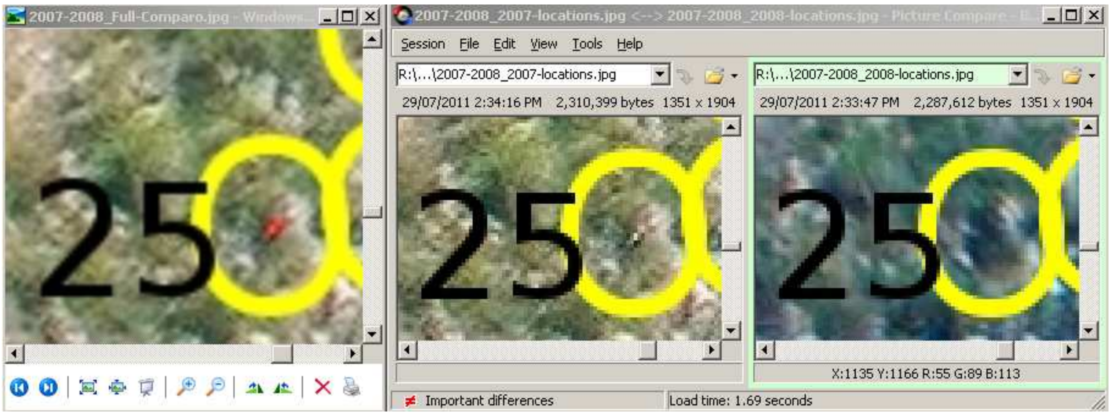

Figure 52. Detail comparison on South face, from West

Vegetation 20%

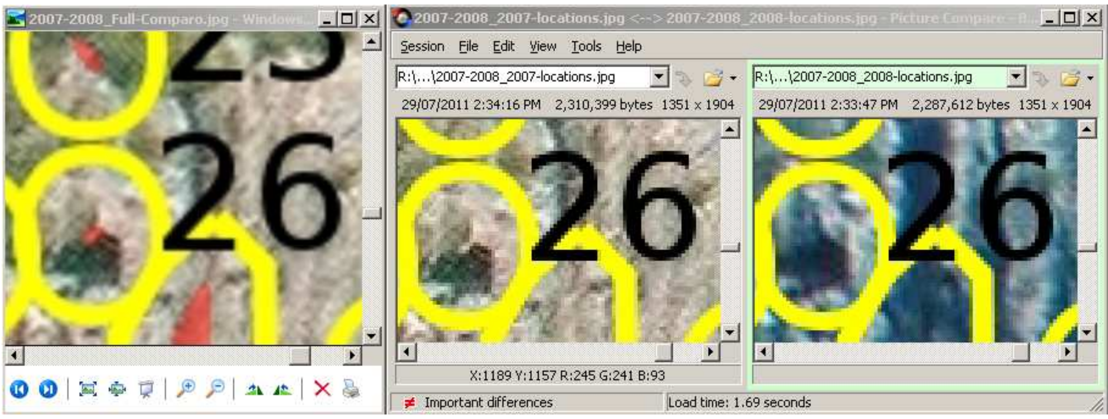

Figure 53. Detail comparison on South face, from West

Vegetation/Shadow/Rockfall 20%

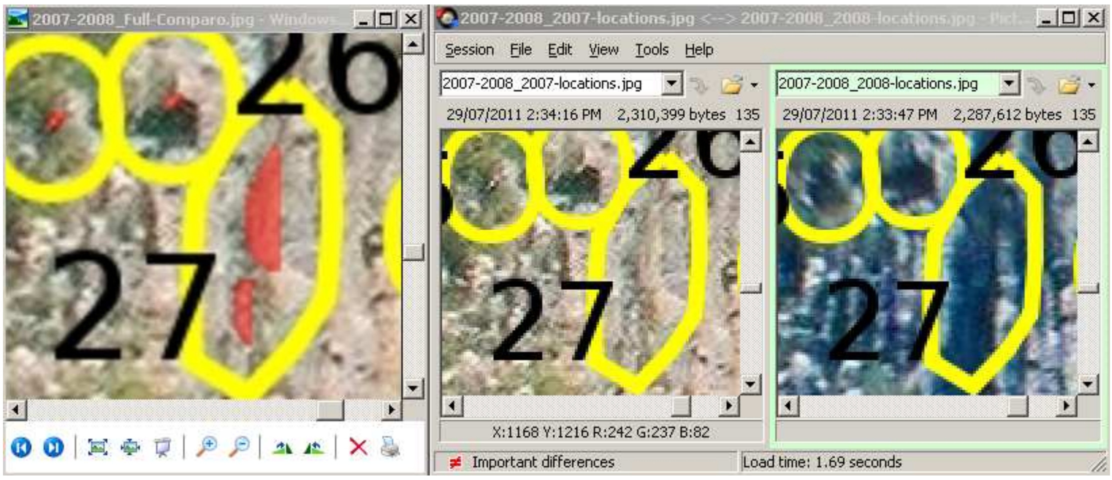

Figure 54. Detail comparison on South face, from West

Shadow 5%

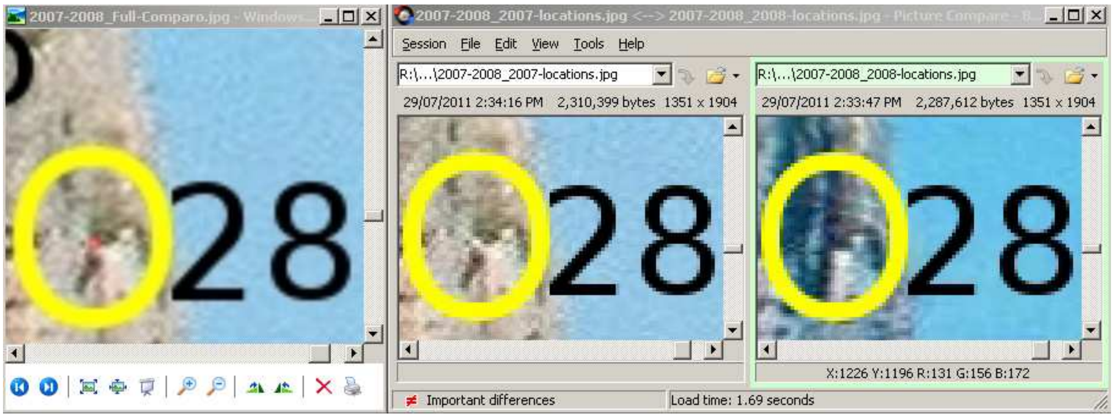

Figure 55. Detail comparison on South face, from West

Vegetation/Shadow/Rockfall 20%

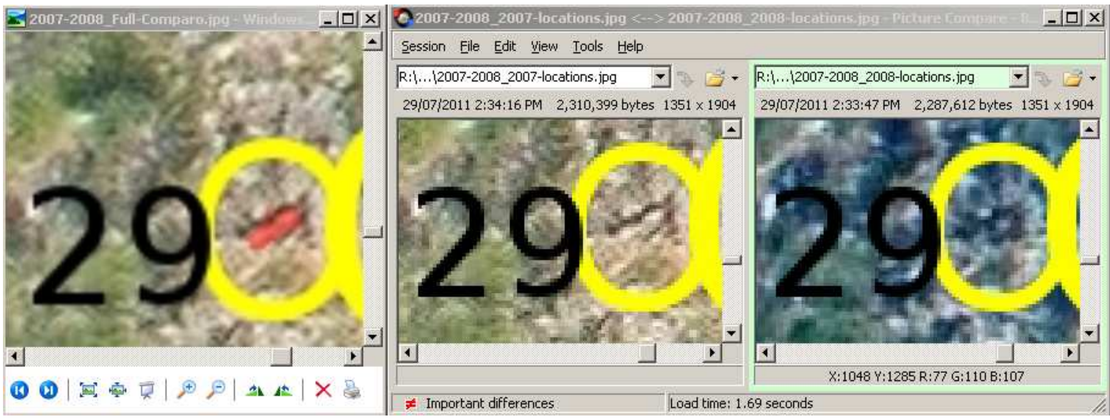

Figure 56. Detail comparison on South face, from West

Vegetation/Shadow 5%

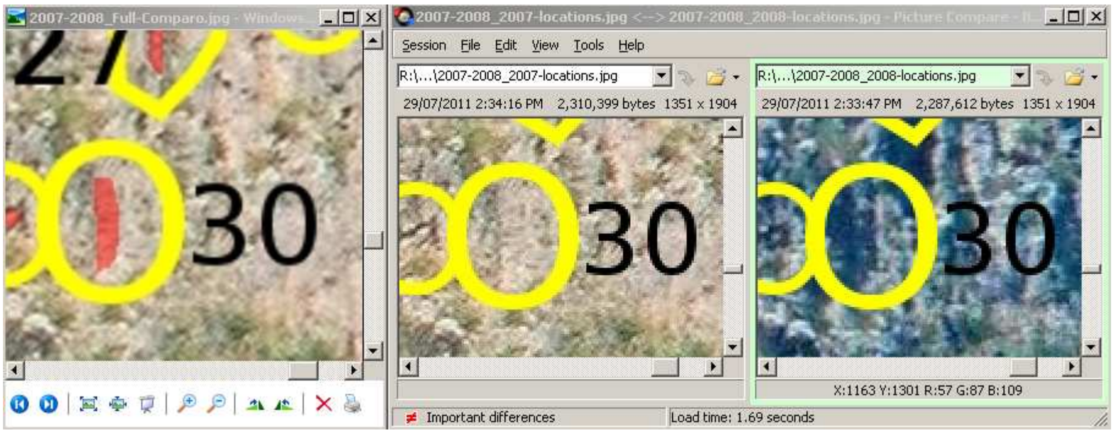

Figure 57. Detail comparison on South face, from West

Vegetation/Shadow 5%

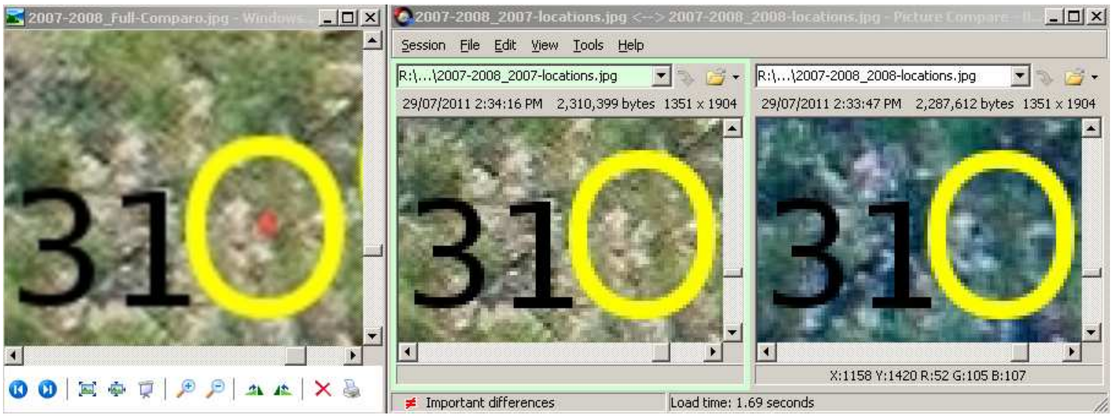

Figure 58. Detail comparison on South face, from West

Vegetation/Shadow 5%

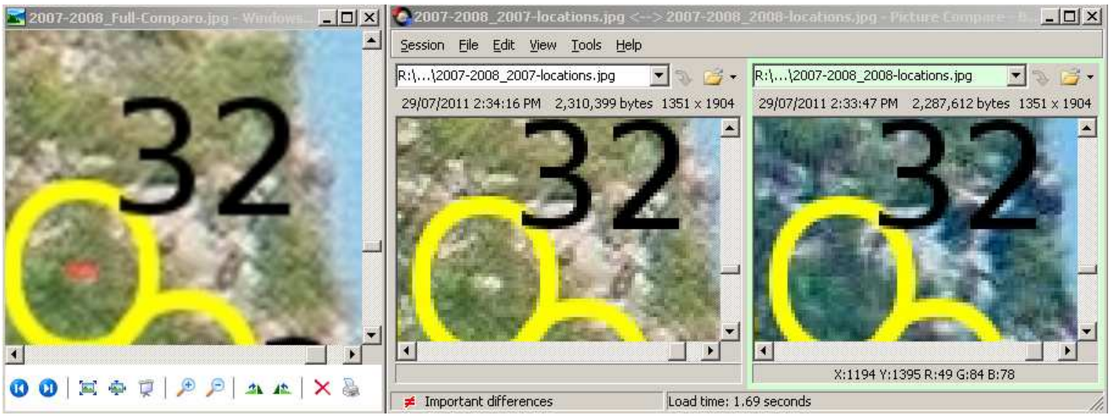

Figure 59. Detail comparison on South face, from West

Vegetation 5%

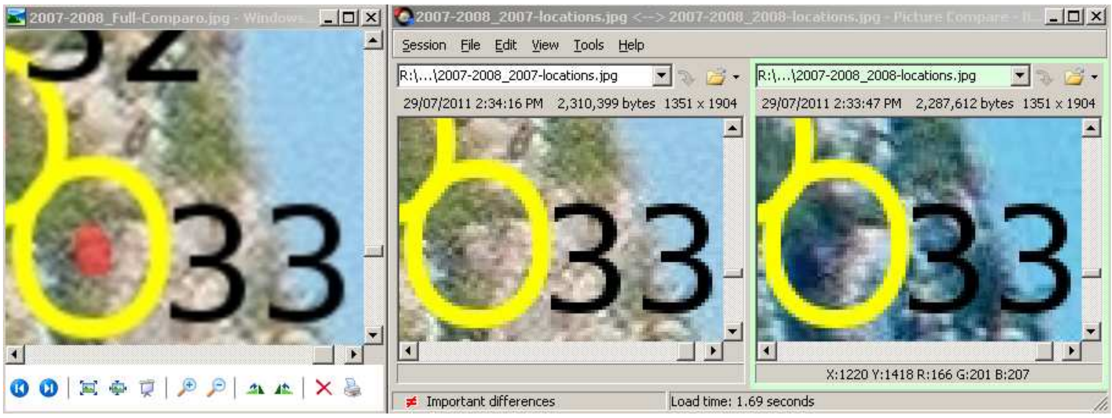

Figure 60. Detail comparison on South face, from West

Rockfall/Vegetation 50%

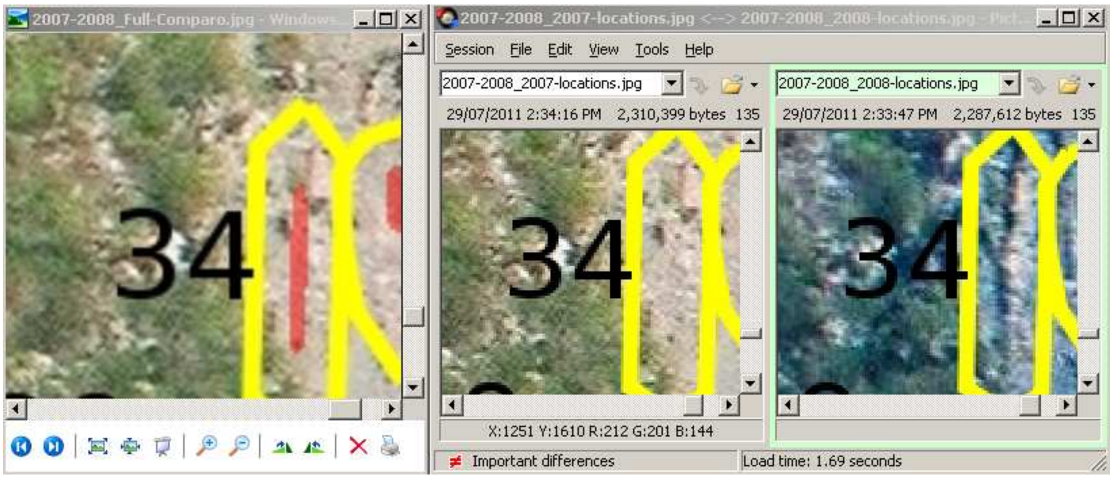

Figure 61. Detail comparison on South face, from West

Shadow 1%

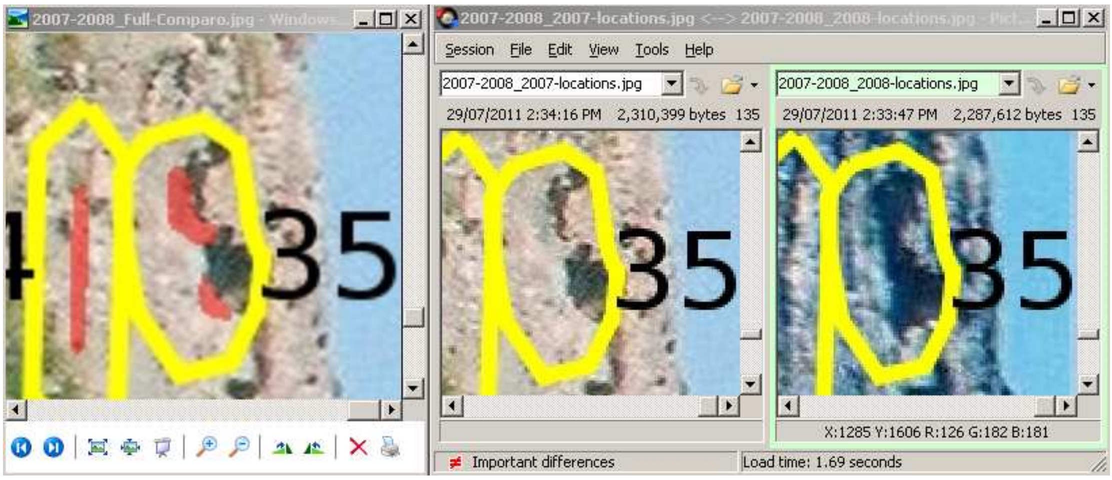

Figure 62. Detail comparison on South face, from West

Shadow 5%

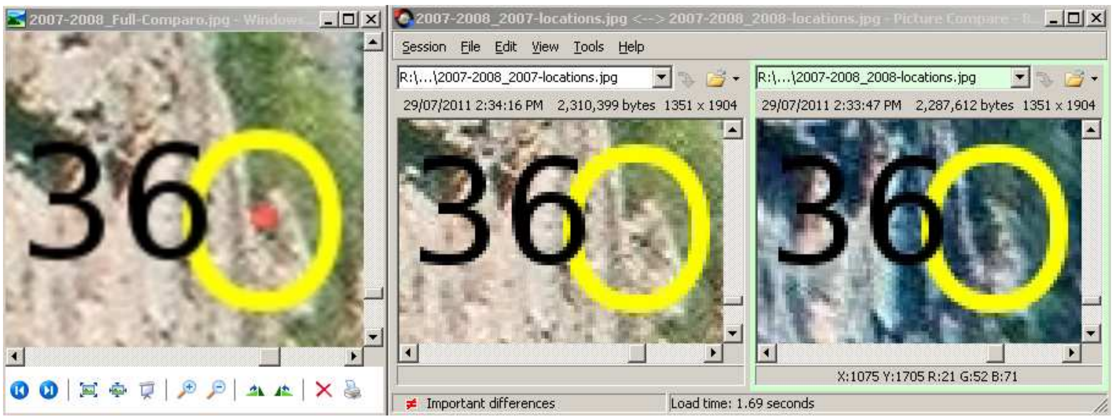

Figure 63. Detail comparison on South face, from West

Rockfall/Vegetation 50%

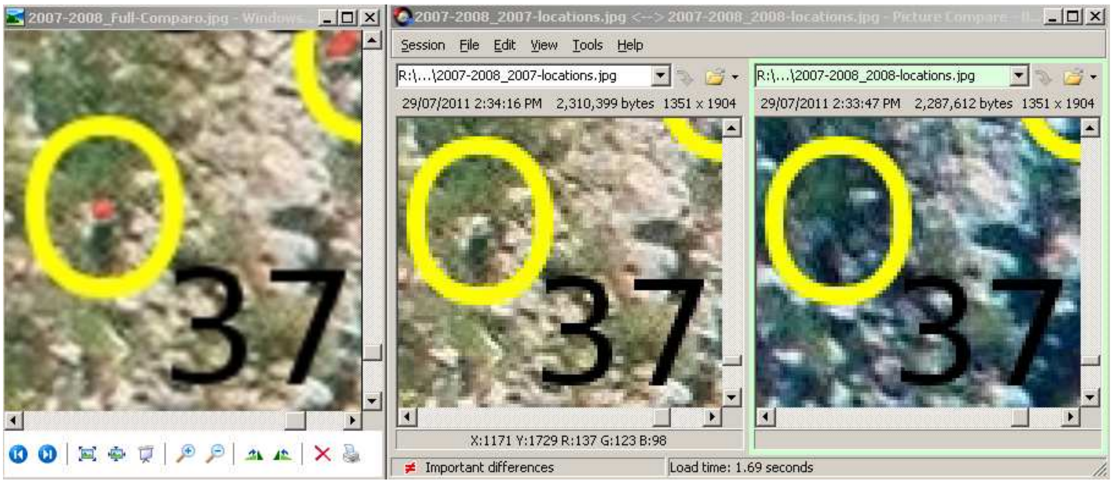

Figure 64. Detail comparison on South face, from West

Rockfall/Vegetation 50%

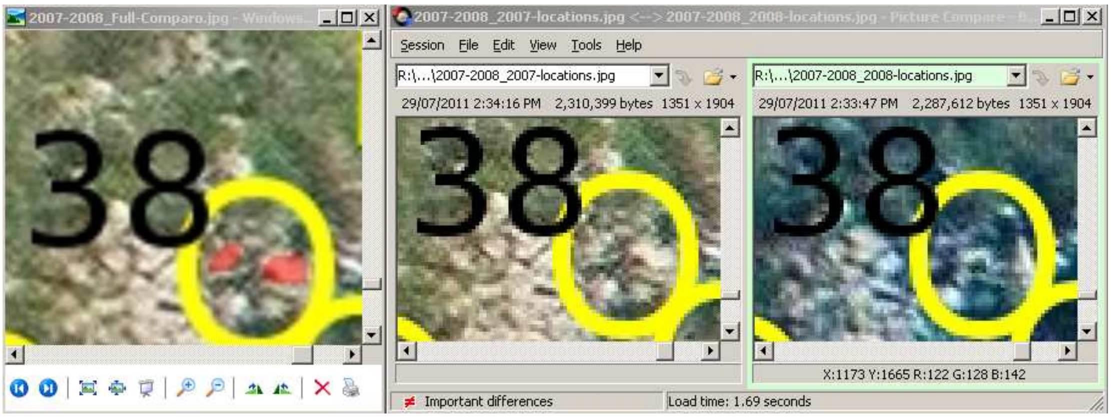

Figure 65. Detail comparison on South face, from West

Vegetation/Shadow 5%

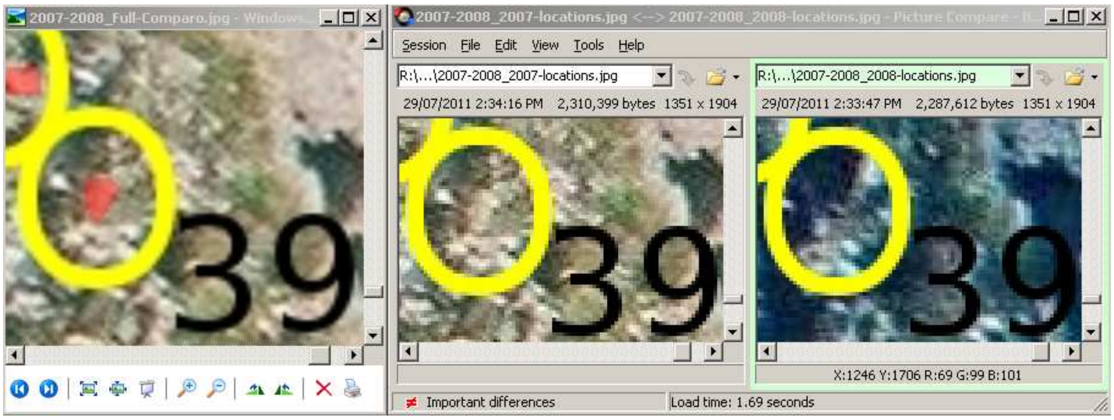

Figure 66. Detail comparison on South face, from West

Rockfall 50%

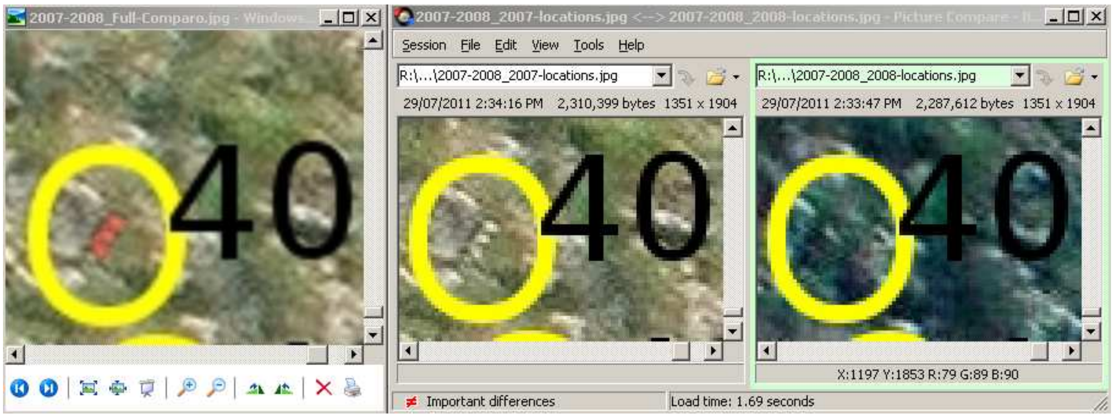

Figure 67. Detail comparison on South face, from West

Vegetation/Shadow 5%

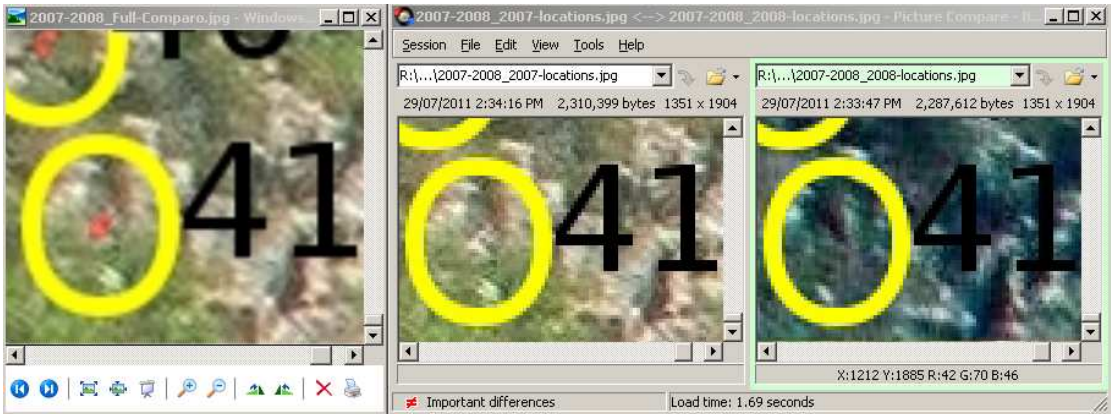

Figure 68. Detail comparison on South face, from West

Vegetation 20%

10.1.3.3 South Face – 2007-2008

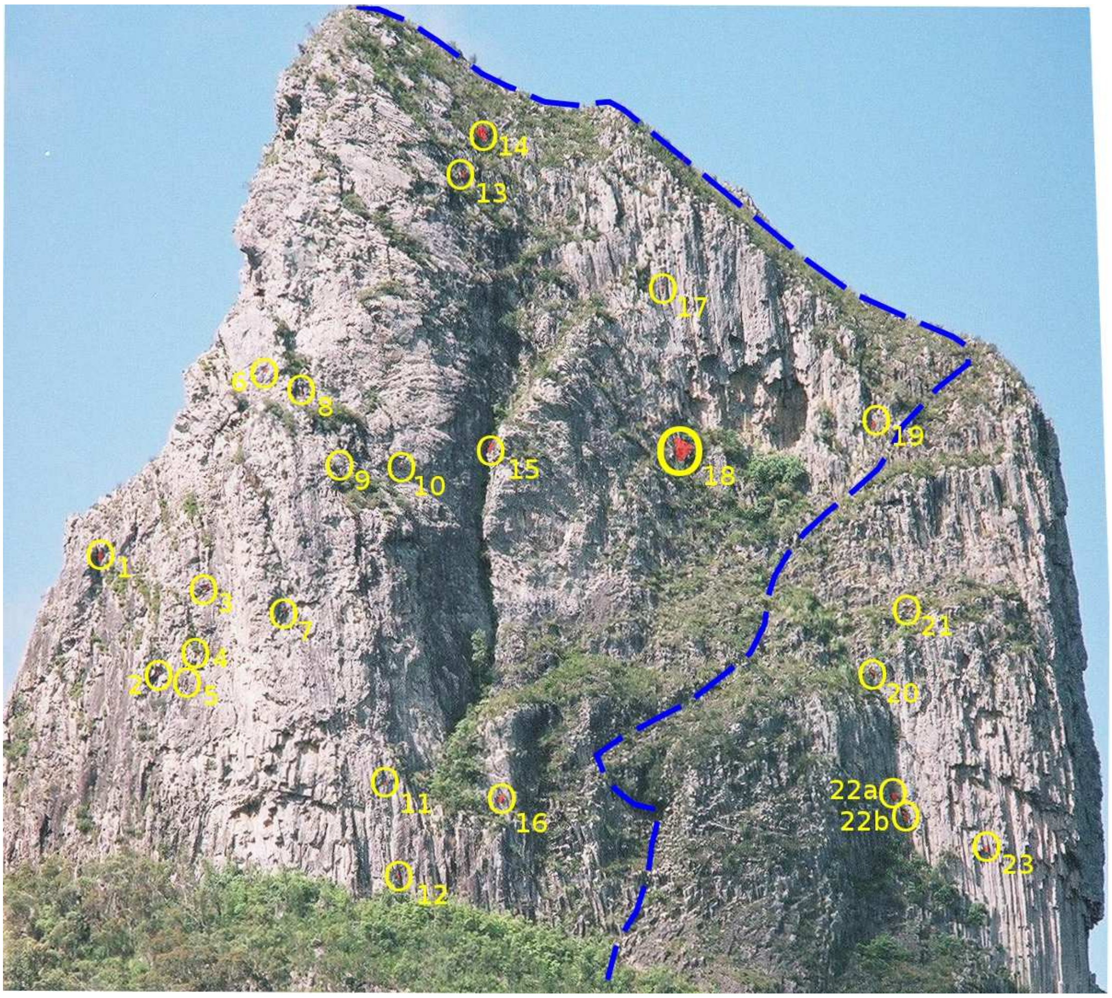

Figure 69. South face visual anomalies - 2007-2008 (photographs in this section taken by Mark Gamble)

Object #	Speculative Explanation (for estimation purposes)	Est % likelihood as Rockfall	Object size (pixels)	Est depth (pixels)	Object area m2	Est object volume m3	Vol in cu-ft	Probability adjusted fall volume (m3)
1	Rockfall/Shadow	80%	41	3	0.837	0.359	12.7	0.287
2	Shadow	1%	9	3	0.184	0.079	2.8	0.001
3	Rockfall/Shadow	50%	12	2	0.245	0.070	2.5	0.035
4	Vegetation/Rockfall	20%	5	2	0.102	0.029	1.0	0.006
5	Shadow/Rockfall	20%	4	2	0.082	0.023	0.8	0.005
6	Shadow	5%	11	2	0.224	0.064	2.3	0.003
7	Shadow/Rockfall	20%	11	2	0.224	0.064	2.3	0.013
8	Shadow	5%	12	2	0.245	0.070	2.5	0.003
9	Shadow	1%	4	2	0.082	0.023	0.8	0.000
10	Rockfall/Shadow	50%	6	2	0.122	0.035	1.2	0.017
11	Rockfall/Shadow	50%	12	1	0.245	0.035	1.2	0.017
12	Rockfall/Shadow	50%	16	2	0.327	0.093	3.3	0.047
13	Vegetation/Rockfall	20%	25	2	0.510	0.146	5.1	0.029
14	Vegetation/Rockfall	20%	121	10	2.469	3.528	124.6	0.706
15	Shadow/Rockfall	20%	46	4	0.939	0.536	18.9	0.107
16	Rockfall/Shadow/Vegetation	50%	41	4	0.837	0.478	16.9	0.239
17	Shadow/Rockfall	20%	12	2	0.245	0.070	2.5	0.014
18	Shadow	1%	276	13	5.633	10.461	369.4	0.105
19	Shadow/Rockfall	5%	24	2	0.490	0.140	4.9	0.007
20	Vegetation/Rockfall	20%	22	2	0.449	0.128	4.5	0.026
21	Vegetation/Shadow/Rockfall	20%	11	2	0.224	0.064	2.3	0.013
22a	Vegetation/Shadow/Rockfall	20%	39	5	0.796	0.569	20.1	0.114
22b	Vegetation/Shadow/Rockfall	20%	37	3	0.755	0.324	11.4	0.065
23	Rockfall/Shadow	80%	27	3	0.551	0.236	8.3	0.189
	Est no of events:	6.5		Estimated rockfall on S face in 2007-2008:				2.047 m3
	Average fall size:	0.316 m3						
		Pixel size (m):	0.1428571					

Table 17. Summary of mismatched objects – South face – 2007-2008

Using the sum of the individual probabilities that each of these image anomalies is a rock fall incident, it is predicted to be most probable that there were 6 to 7 incidents of significant rock fall averaging 0.32m^3 each off this face, totalling a volume of 2.05m^3 during the year. Given the vagaries of this method of analysis and the breadth of interpretation possible, this still fits well at a broad statistical level with the Coffey (Coonowrin) 1999 [1] prediction that there would be an average rockfall of 3 to 4 falls per year each of 0.5m^3, totalling 1.5m^3 per year, and those predicted rock frequencies seem to be upheld by this observation.

Note that there is a crossover between the analysis for the West and the South faces and this is examined in *South and West Faces Correlated – 2007-2008* below.

10.1.3.4 South Face – 2007-2008 – Detailed Possible Rockfall Sites

The following are the records of examination used to determine the probability that each is a site of rock fall. This is still only an approximate probability and each may be caused by other visual effects, however a “best and fairest” estimate was made for engineering risk analysis purposes.

Each figure has table cells showing the speculative explanation (for estimation purposes) and the estimated % likelihood that the anomaly is in fact rockfall.

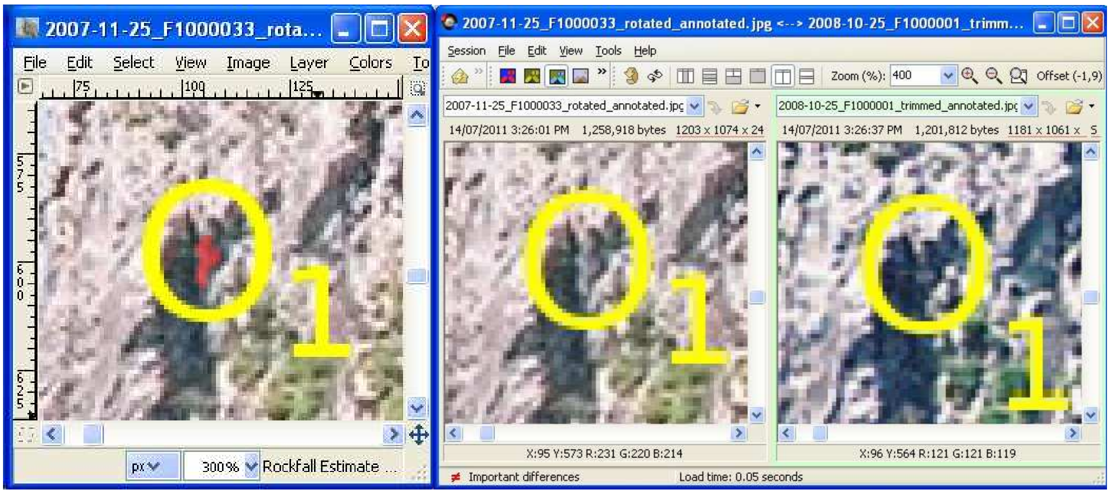

Figure 70. Detail comparison on South face

Rockfall/Shadow 80%

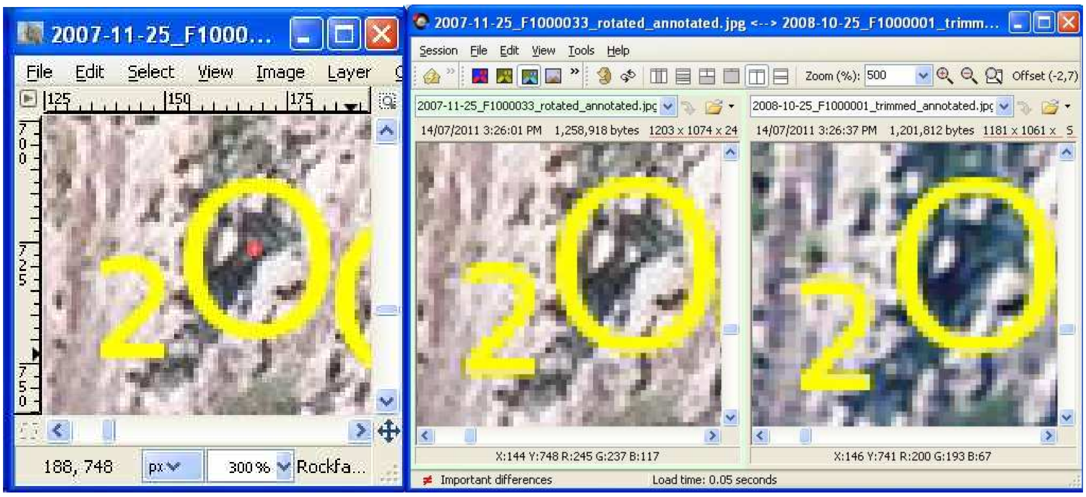

Figure 71. Detail comparison on South face

Shadow 1%

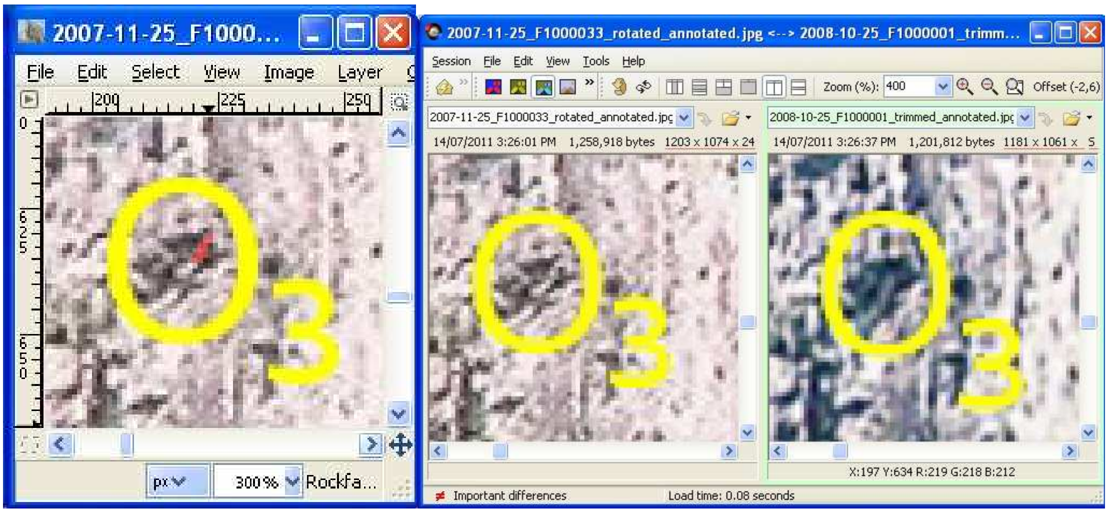

Figure 72. Detail comparison on South face

Rockfall/Shadow 50%

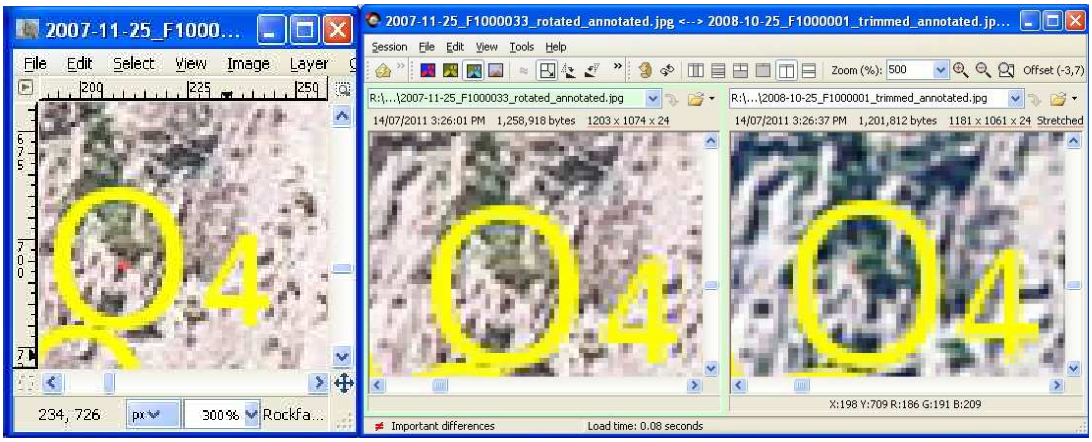

Figure 73. Detail comparison on South face

Vegetation/Rockfall 20%

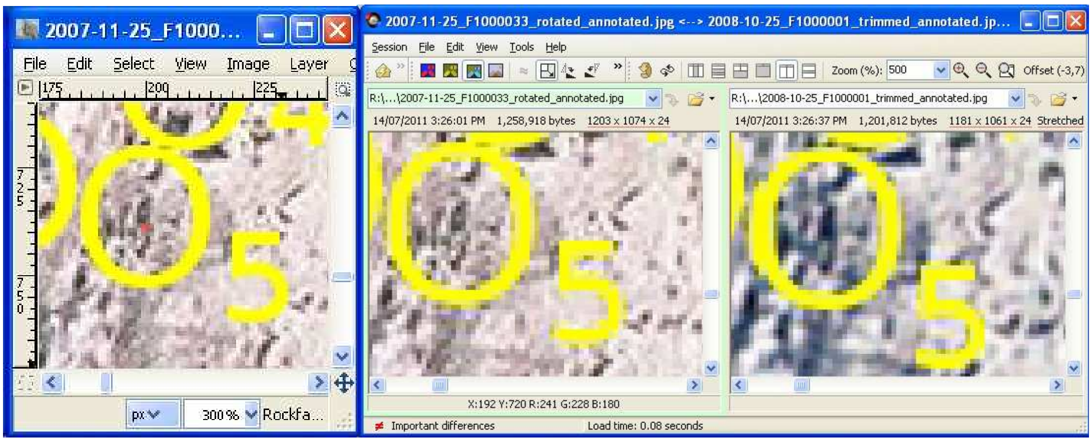

Figure 74. Detail comparison on South face

Shadow/Rockfall 20%

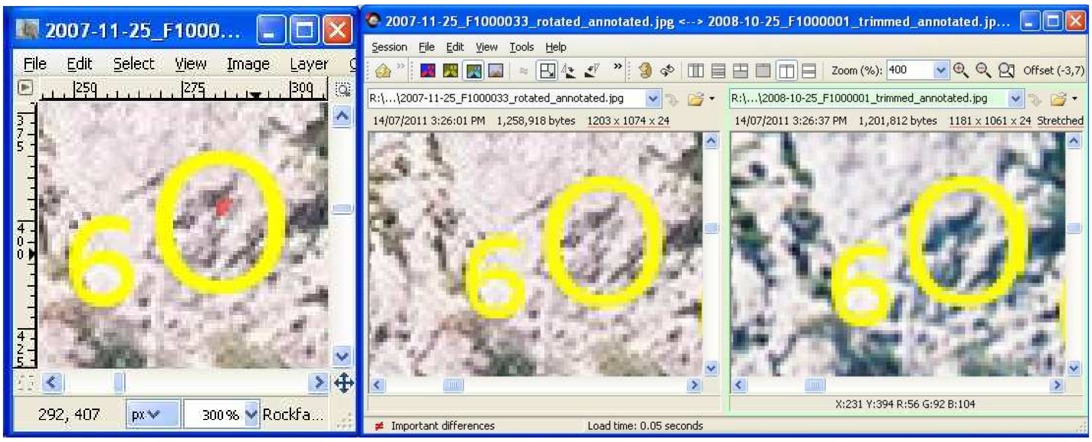

Figure 75. Detail comparison on South face

Shadow 5%

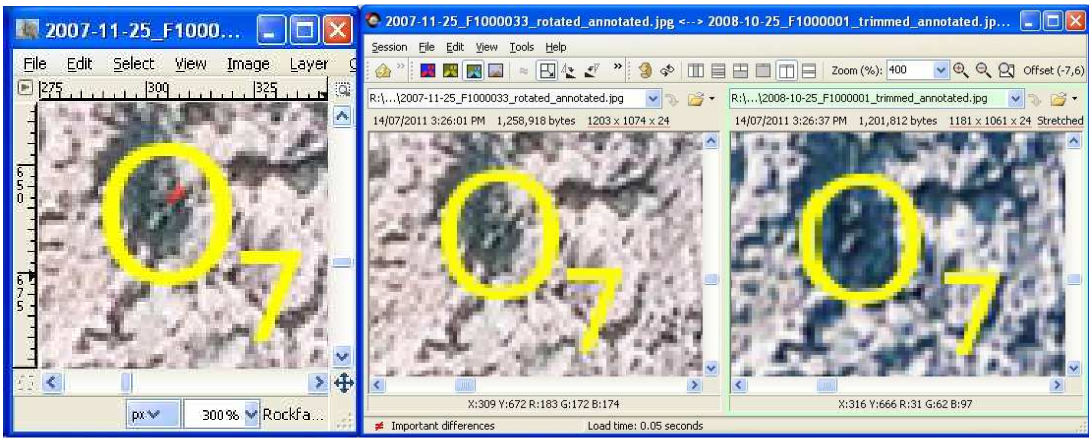

Figure 76. Detail comparison on South face

Shadow/Rockfall 20%

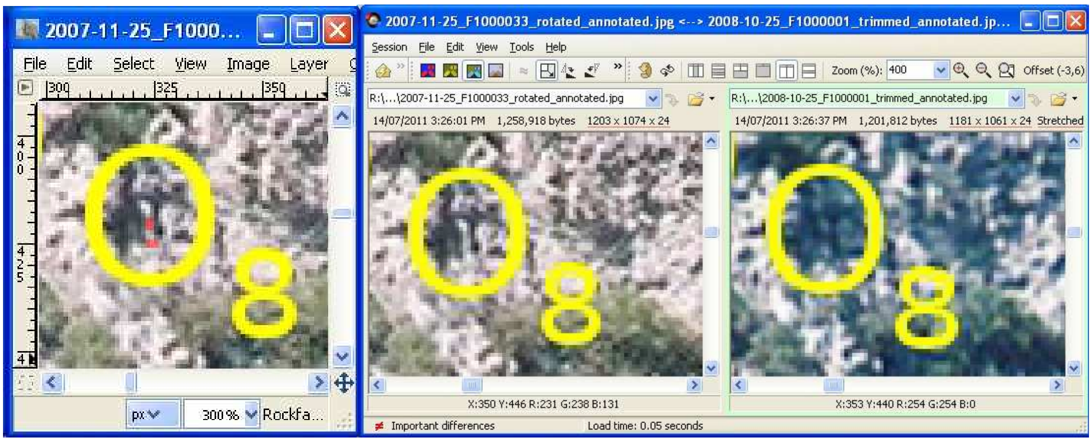

Figure 77. Detail comparison on South face

Shadow 5%

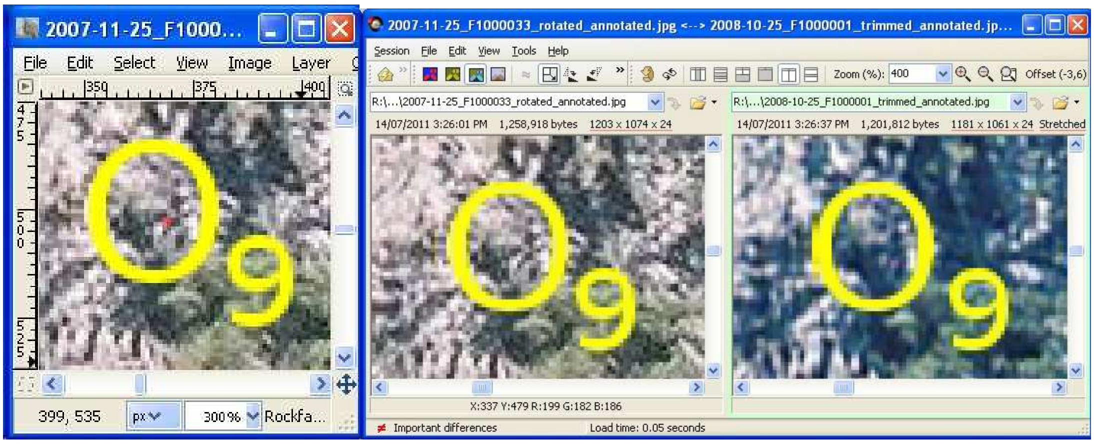

Figure 78. Detail comparison on South face

Shadow 1%

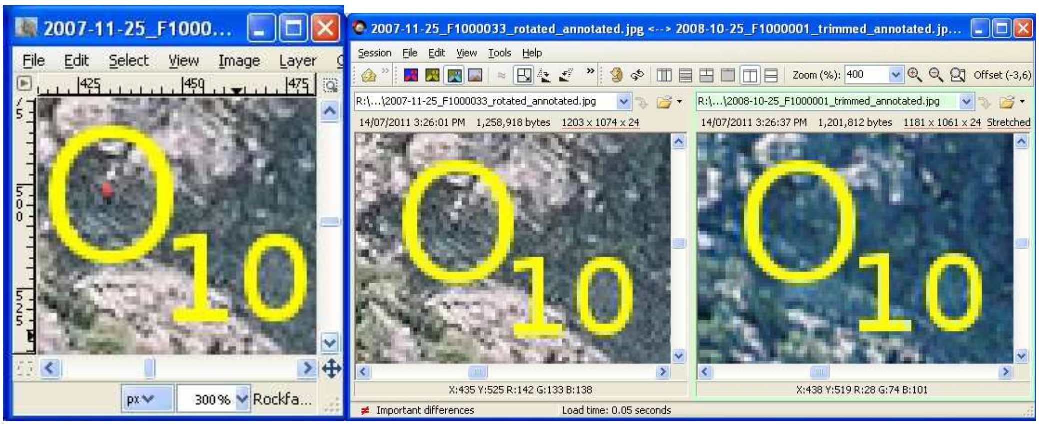

Figure 79. Detail comparison on South face

Rockfall/Shadow 50%

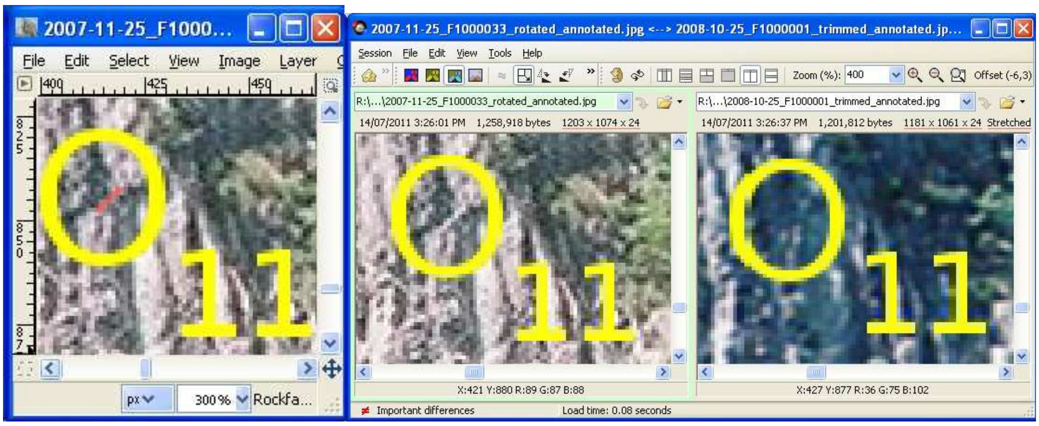

Figure 80. Detail comparison on South face

Rockfall/Shadow 50%

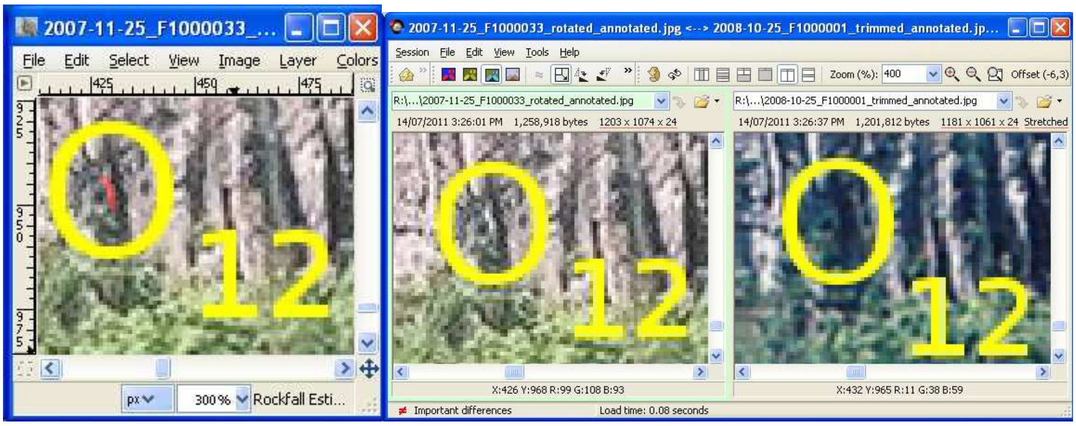

Figure 81. Detail comparison on South face

Rockfall/Shadow 50%

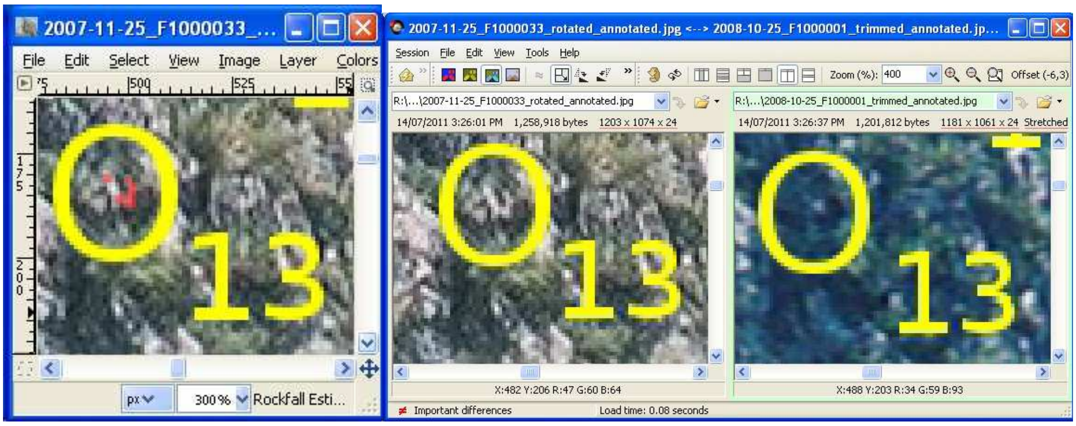

Figure 82. Detail comparison on South face

Vegetation/Rockfall 20%

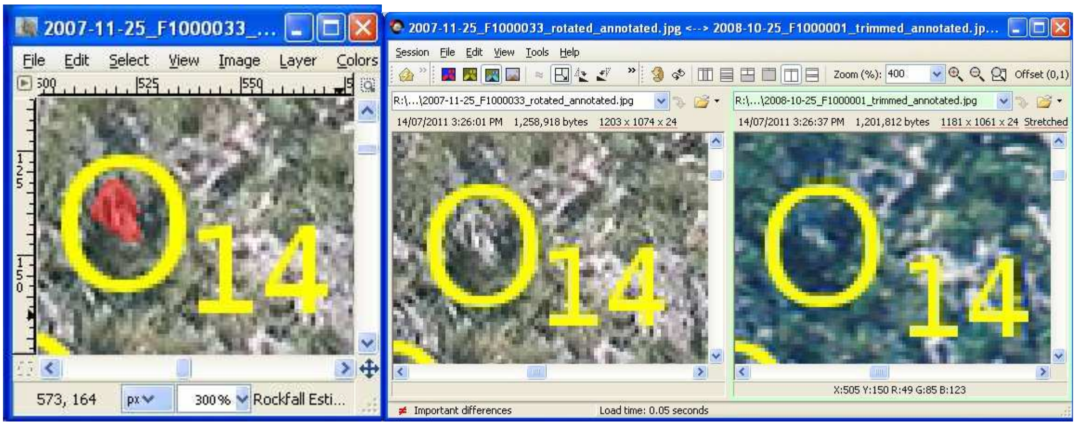

Figure 83. Detail comparison on South face

Vegetation/Rockfall 20%

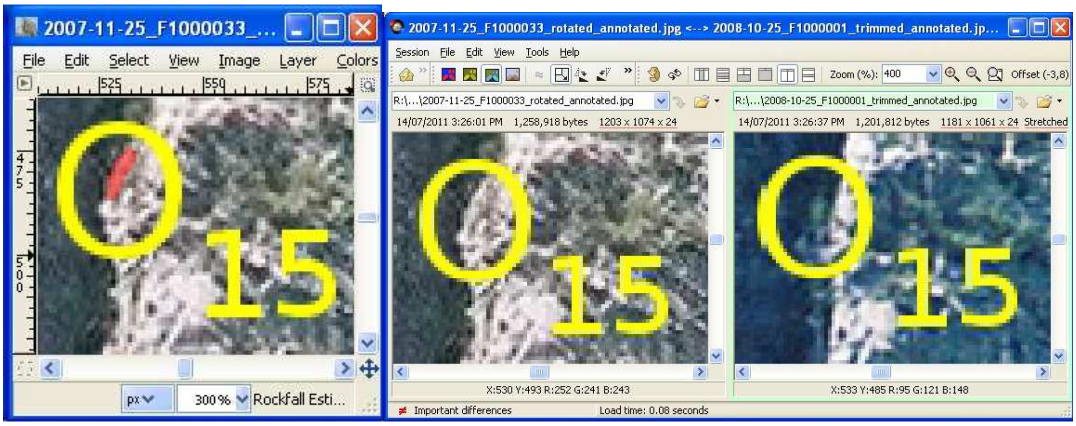

Figure 84. Detail comparison on South face

Shadow/Rockfall 20%

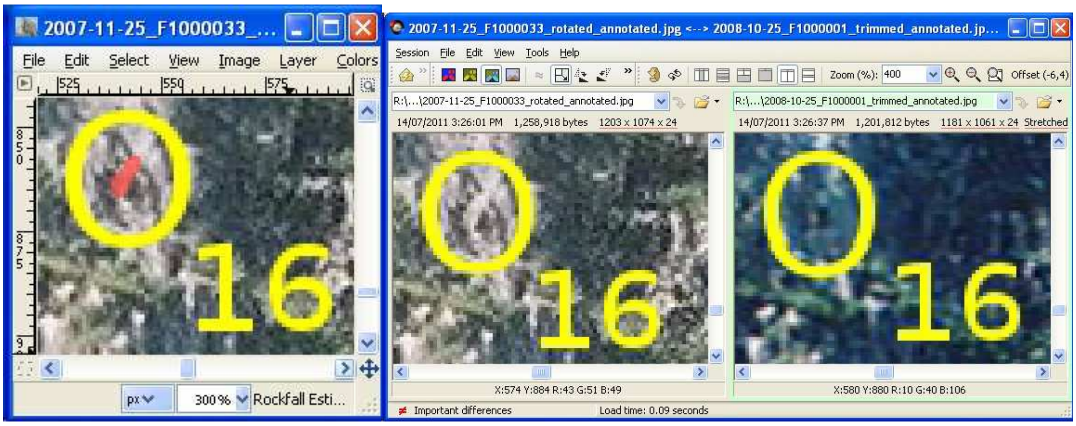

Figure 85. Detail comparison on South face

Rockfall/Shadow/Vegetation 50%

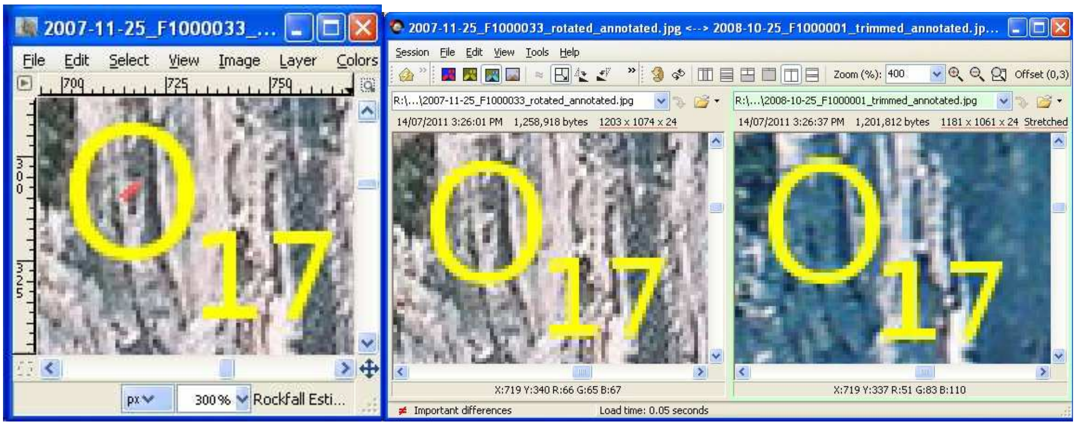

Figure 86. Detail comparison on South face

Shadow/Rockfall 20%

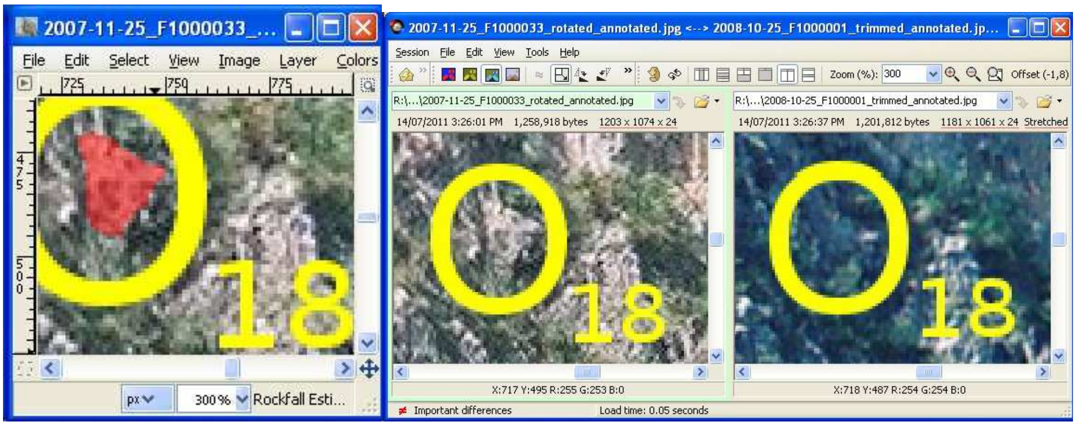

Figure 87. Detail comparison on South face

Shadow 1%

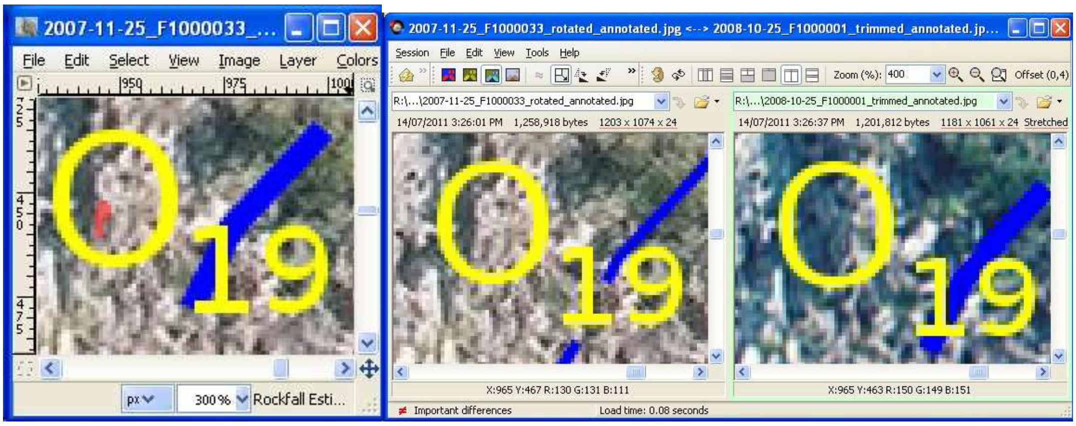

Figure 88. Detail comparison on South face

Shadow/Rockfall 5%

Figure 89. Detail comparison on South face

Vegetation/Rockfall 20%

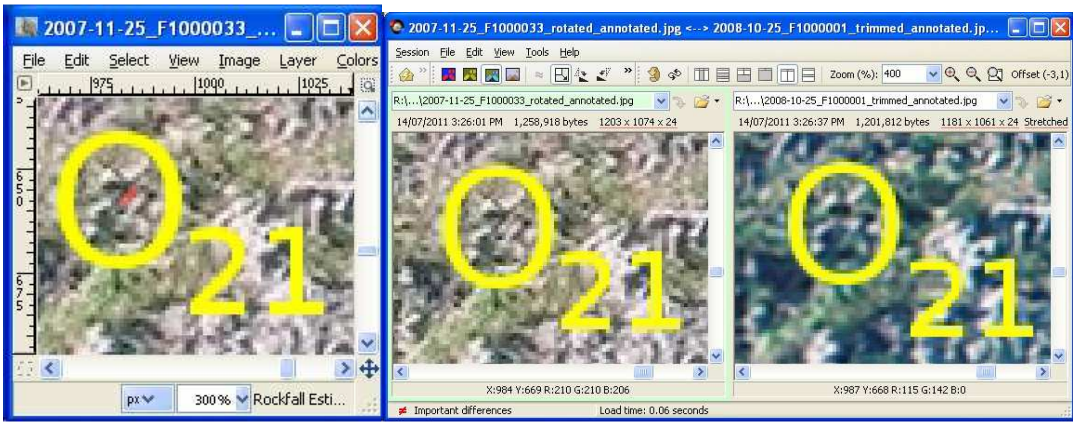

Figure 90. Detail comparison on South face

Vegetation/Shadow/Rockfall 20%

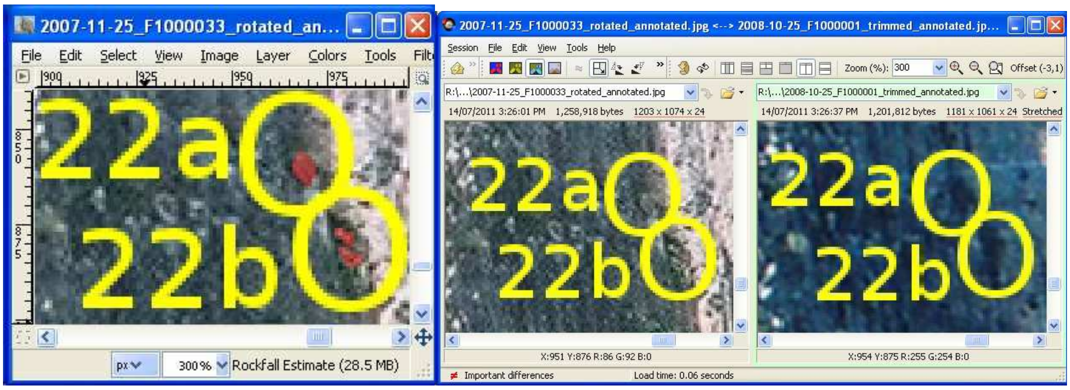

Figure 91. Detail comparison on South face

Vegetation/Shadow/Rockfall 20%

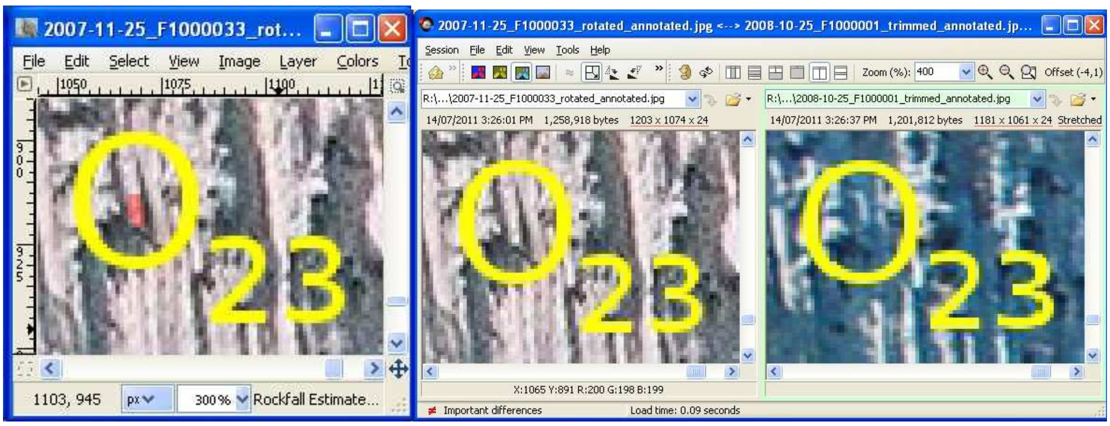

Figure 92. Detail comparison on South face

Rockfall/Shadow 80%

10.1.3.5 South and West Faces Correlated – 2007-2008

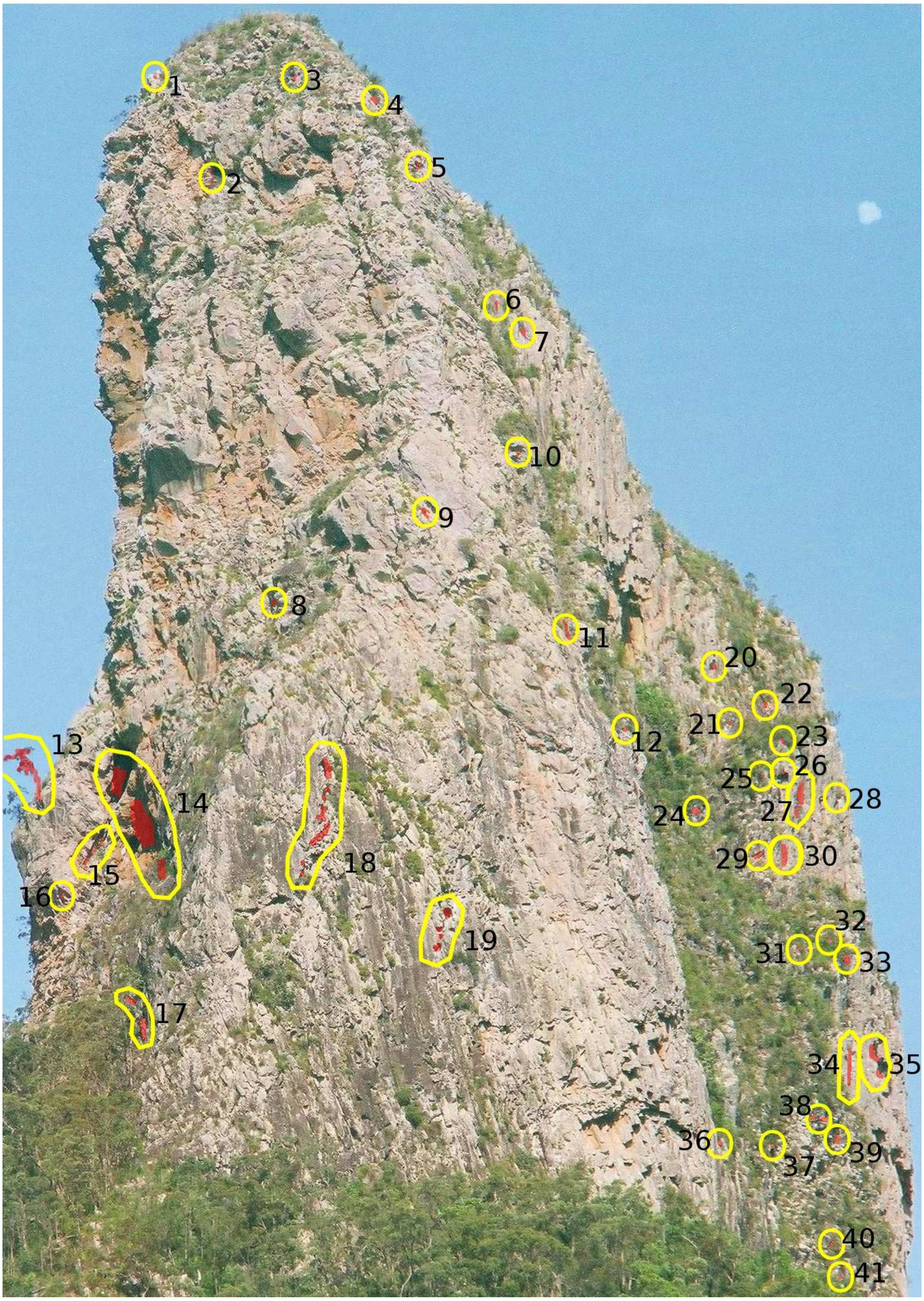

Figure 93. Mismatched objects from the West, with South face objects from 20-41

It's important to note that the objects numbered 20 to 41 above are all located on the South face, and better represented by higher resolution below. The analyses above presume that the objects that are given probabilities as rockfall are all independently valid without reference to the analysis from the other camera angle.

A more complicated approach would attempt to correlate the objects in the West face photo to the objects in the South face photo. This was not undertaken due to lack of additional time required to undertake that. At a basic level the following object equations were estimated: West18=South1, W19=S2, W36=S16, W20=S19. Deeper analysis of this could be performed, but no additional critical information is expected to arise as a consequence.

As a basic premise, it could be argued that 50% of the objects in the West photo (all the objects 20-41) are more adequately covered in the analysis of the South photo and can be discounted from that analysis, halving the rockfall estimates from that face. That would result in the gross fall on those two faces being re-evaluated to around 10 falls, averaging 0.3m^3 and totalling 3m^3 per year.

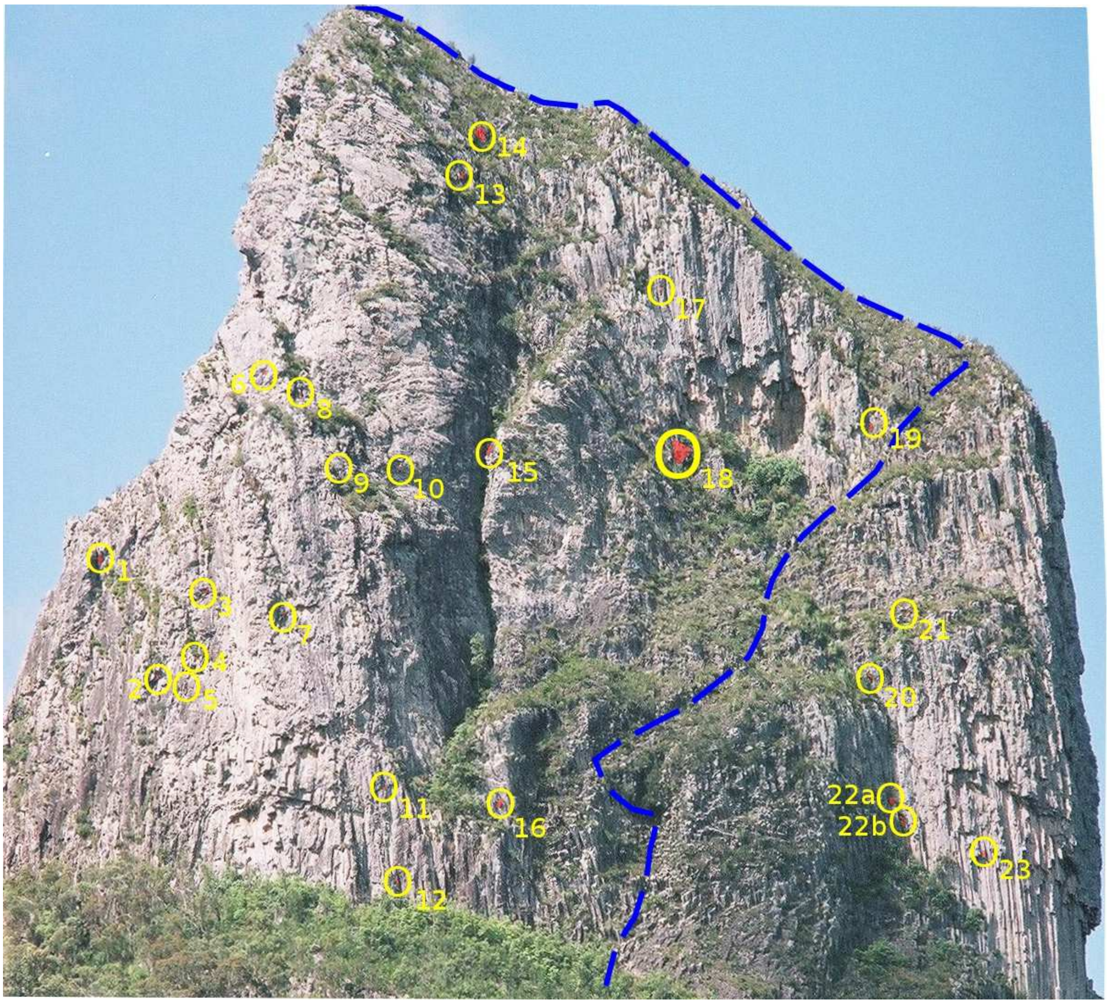

Figure 94. Mismatched objects from the South, with West face objects from 1-9

10.1.3.6 North Face – 2007-2008

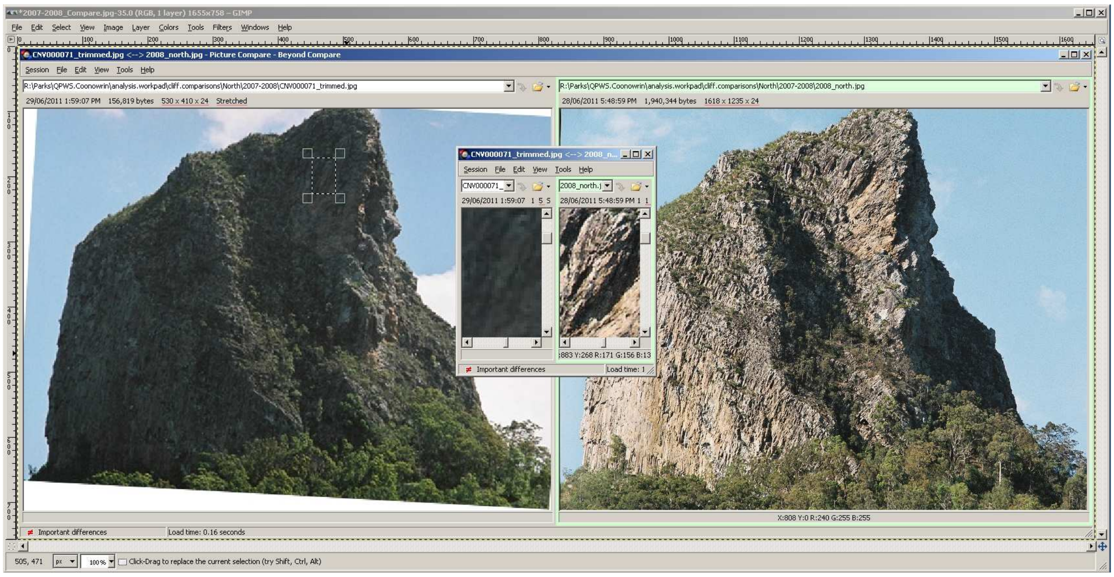

Figure 95. Comparing objects on North face (photographs taken by Mark Gamble)

A detailed examination of these photos was undertaken, but the different shadowing made the task quite difficult. It was still possible to make a fair assessment of the face as displayed in the above graphic, and no specific loss of rock from this face was identified during this period.

10.1.3.7 East Face – 2007-2008

There was no detailed photographic comparison performed for the East face for this period. Photographs explicitly capturing this face were not found among the pool of materials during the analysis phase.

10.1.3.8 One Year Contemporary Comparison Summary

Overall all faces are mostly unchanged over the year from 2007 to 2008. There are a few optical mismatches that may indicate some small-scale rock fall on the West, and South faces, but this approximates to an amount within the expectations of the theoretical rockfall quantifications in *Establishing Natural Hazard Mechanisms and Quantities* above.

Of particular significance is that there are few if any verified falls from areas marked in Coffey (Coonowrin) 1999 [1] as “very high risk”. This validates a theory that those surfaces are not suffering from an accelerated rock fall rate, and therefore designation of those areas of the rock surface as “very high risk” does not extend to forming expectations that there will be a high frequency of rock fall from those faces during a typical one year timeframe.

Also of note is the fact that there are very few identified fall sites directly impacting the common walking track route of the 1990s, indicating that the theoretical risk analysis above that assumes a uniform distribution of rock fall is conservative in this manner, in that less fall candidate sites are observed over the track route and more fall candidate sites are observed over other areas that are not above the track path.

10.2 First Hand Examinations

10.2.1 Site Visits

Date	Activity
2007-11-25	Initial survey of bushland at skirt. Circumnavigate base and look for signs of significant change since 1998.
2007-12-03	Ascend North face to “Mank Master” cave mouth, examine brown crust on rock. Circumnavigate base and examine columns and erosion patterns in East caves. Ascend to South face caves (“Salmon’s Leap” trail) and examine structures in cave.
2008-10-10	Circumnavigate base and look for signs of significant changes since 2007 visits.
2008-10-25	Circumnavigate base and look for signs of rockfall, examine columns and erosion patterns in East caves. Ascend and examine South face caves.
2008-11-08	Ascend North East ridge, taking photographs of Coffey’s block from the East. Also considering alternative routes vs South face. Thunderstorm retired the trip early.
2008-11-14	Wet weather. Attend East face caves and record 1890-1910 inscriptions.
2008-11-23	Circumnavigate base and look for signs of rockfall.
2009-07-12	Circumnavigate base and look for signs of significant changes since 2008 visits. Ascend and look for any changes on track since 2008. Descend via Eastern slopes and look at rock debris in gullies.
2009-07-18	Ascend North face caves (“Mank Master” trail). Examine and record rock formations in North caves. Examine and record brown crust on North face.
2009-07-26	Take SES on a site visit. Circumnavigate base and look for signs of recent rockfall.
2009-08-15	Take SES on a site visit. Circumnavigate base and look for signs of recent rockfall. Ascend to South face caves (“Salmon’s Leap” trail) and examine structures in cave.
2009-10-18	Ascend into North face caves (“Mank Master” trail). Examine and record rock formations in North caves, looking for changes versus photos taken in 1993, and versus video taken 2009-07-18. Wet weather obliged an exit from the top mouth of the cave to ground level.

Table 18. Site visit schedule

10.2.2 Fallen Rock Around the Skirt

Examinations of the ground around the base of the mountain found evidence of probable recent falls on site.

In summary, over the two year study:

- No specific fall sites were noted on the South and West sides, although there was rock on the ground of an indeterminate age. None looked particularly fresh or interesting.
- There were four specific incidences found of a single rock fallen to the ground, all below the East face. The sizes were estimated as $0.24m^3$, $0.11m^3$, $0.08m^3$, and 0.024m3. Two fell from body height (0-3m) off the cliff and remained where they had fallen, and would not have presented a human risk. The other two fell from an indeterminate height and rolled between 10 and 20m.
- There is a single location where small shards of rock have fallen to the ground at an undetermined but obviously accelerated rate compared to the rest of the site. This is under the cave on the North face, below and to the West side of the perched block identified by Coffey (Coonowrin) 1999 [1]. This can be likened to a "glacier" in that the flow of rock fall is predicable in location and path, however it occurs at a geological rate of flow, not a flow observable in a human timeframe.

These are the details of the specific fall sites identified during the study.

10.2.2.1 Rockfall found Below the East Face

The following four instances of fallen rock were found over the two year study period. Various walks further down the slopes found no evidence of fresh falls, only non-current ones (as evidenced by botanical growths on and around them). Hence it is proposed that the short rolling distance of the ones sighted is the most typical ground action to be expected once pillars have fallen from the cliff to ground: a rolling distance of about 10m on average.

There is a ravine some 50m to 100m below the East face where a field of fallen pillars are lying in a jumble. This presents as being of great geological age. I consider it worth investigating as to whether that feature is occurring as a slumping action riding the erosion of the mass of earth down the eastern slope in millimetres per millennia, rather than having fallen in one great dramatic fall.

10.2.2.1.1 Fall Site 1

A single pillar, approximately 0.24 m^3 (est 1.5x0.4x0.4), was found on the slope approximately 20m from the base of the East cliffs, between the East and South East caves on 2008-11-23. This appeared to have some crushed grass and plants in an apparent path behind it, and it gave the impression of having fallen sometime in the recent year. The location was not expressly recorded, and in a later trip efforts to exactly locate it were unsuccessful. The source location of the pillar on the cliff line was not ascertained.

Figure 96. Fallen Pillar, East face

10.2.2.1.2 Fall Site 2

A single pillar, approximately 0.11 m^3 (est 1.2x0.3x0.3), broken into pieces, was found on the slope approximately 10m from the base of the East cliffs, some 10m North of the East caves on 2008-11-23. There were deformed plants and powdered debris and this appeared to have fallen sometime in the recent months. The source location of the pillar on the cliff line was not ascertained.

Figure 97. Plant damage

Figure 98. Fallen Pillar, East face

10.2.2.1.3 Fall Site 3

A piece, approximately 0.080 m^3 (est 0.5x0.4x0.4), was found on the ground at the East caves on 2009-07-26, approximately 1m from the cliff base. It had fallen within the recent year, as it had not been observed on the ground prior to this visit. This had fallen from a height of less than 1m above ground level as it was a weathered obelisk that had eroded at a neck and finally snapped off, possibly under its own weight once the neck of the pillar was thinned down to the small area shown below.

Figure 99. Montage - Fallen Block, East face

10.2.2.1.4 Fall Site 4

A piece, approximately 0.024 m^3 (est 0.4x0.3x0.2), was found on the ground at the North East corner on 2009-07-26, approximately 2m from the cliff base. It was estimated to have fallen within the previous fortnight, as the grass beneath it was still dying from light starvation.

Figure 100. Fallen block, East face

Figure 101. Grass decaying

10.2.2.2 Rockfall on the Ground Below the North Cave

Numerous small pieces of broken rock of indeterminate age were found beneath the North face cave ("Mank Master") on every trip, as was the case also during the 1990's. This is the consequence of the erosion and strain patterns observed in later visits that examined the internal structure of the North face cave. This rock can be considered to be falling fairly frequently, due to the nature of the continuous erosion in the cave. It could be estimated within Coffey's original decay frequency that a small fall of a single saucer-sized rock or two might occur once a month. It is also more likely that this might occur during high winds, heavy rain, or during any earth tremor, as the mouth of the cave depicted above serves as a "brimming-full dam" of these shards of rock and cave dust. Any new falls inside the cave first fall onto this perched pile of dust and scree, and some may then fall from the edge of the "dam". This cave is inaccessible to anyone without comprehensive rock-climbing skill and equipment, and as a climbing route it is unattractive in the common sense, being troublesome and extremely "boutique", so there is a minimised chance of people increasing this displacement of rock to the ground below.

Figure 102. Scree below North cave

Going further up the mountain above this debris, the cave on the north face (known as "Mank Master") is identified as the source of the flow of rock.

Figure 103. Looking down at the floor of the cave, from standing inside the cave

And inside the cave, there are numerous (perhaps a dozen) features that present as contributory sources of the flow of rock emitting from the mouth of the cave. This is a sample.

Figure 104. Rock formation inside the North cave

This rock degradation pattern is described further in the section *Examination of "Coffey's Block" / Mank Master Cave* on page 113.

10.2.3 Integrity of the Rock In-Situ in the Face

Use was made of our ability to ascend the faces using common rock-climbing skills and equipment at the disposal of the research team. In doing so we were able to reach parts of the cliff at first hand that the Coffey (Coonowrin) 1999 [1] team were unable to examine except at a visual distance, and which were reported by Coffey (Coonowrin) 1999 [1] as being of significant risk interest.

10.2.3.1 Brown Crust

Coffey (Coonowrin) 1999 [1] make reference to the brown coloured areas of the rock faces as being indicative of "recent rock fall" and thus classified them as "very high risk".

By examining the rock first hand, it was found that the rock's integrity and prior fall age are not closely linked to the brown colouration. The impression that it gives from a distance of being indicative of being a dusty or dirty surface film is deceptive. The brown colouration is a hard crystalline mineral crust of significant geological age. This brown crust was found to be mostly impossible to dislodge by hand, and only yielded by impacting it with a metal tool.

The crust was examined as being both strongly adhered and highly aged in the following locations.

10.2.3.1.1 North Face

The brown mineralisation appears high on the North face, just below the area circled on Coffey (Coonowrin) 1999 [1] as "very high risk".

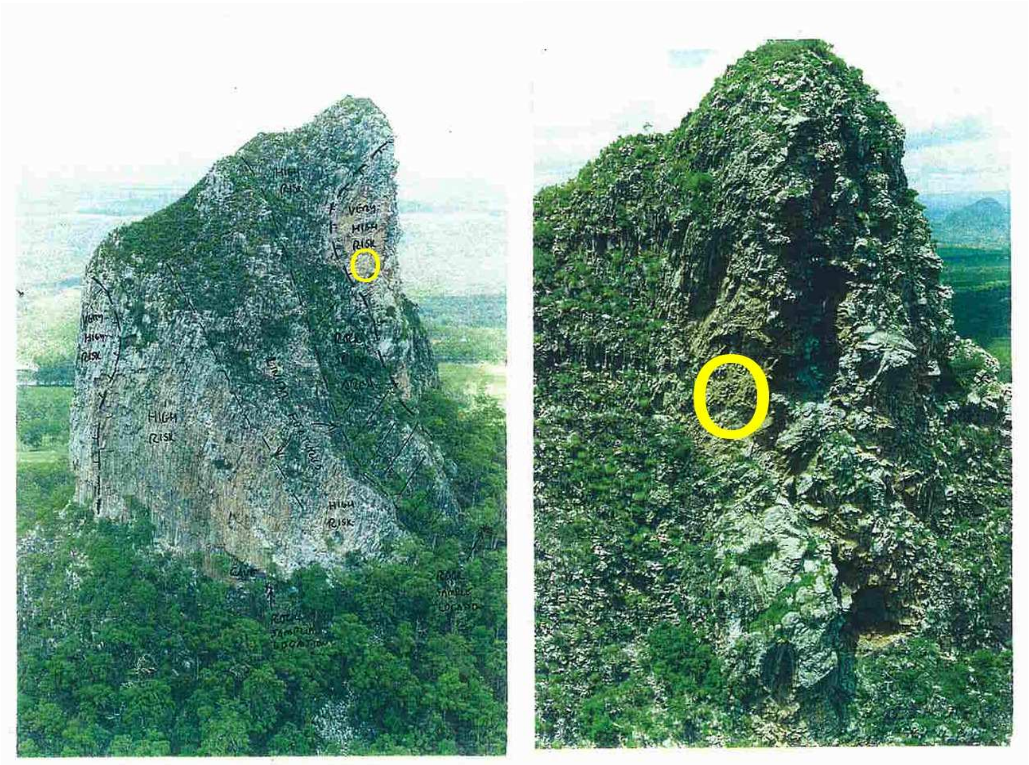

Figure 105. Location under examination on North face (images from Coffey (Coonowrin) 1999 [1])

These are some of the location pictures showing the brown mineral crust in this location first hand:

Figure 106. Looking directly up from the foot of the North face

Figure 107. Looking East along the North face

Figure 108. Brown mineralisation

Figure 109. Brown mineralisation

Figure 110. Testing brown mineralisation for adhesion by hand

Figure 111. Testing brown mineralisation for adhesion by hand

10.2.3.1.2 North Face Cave

The brown mineralisation also appears in the mouth of the cave on the North Face, in the area noted on Coffey (Coonowrin) 1999 [1] as “recent rock fall”.

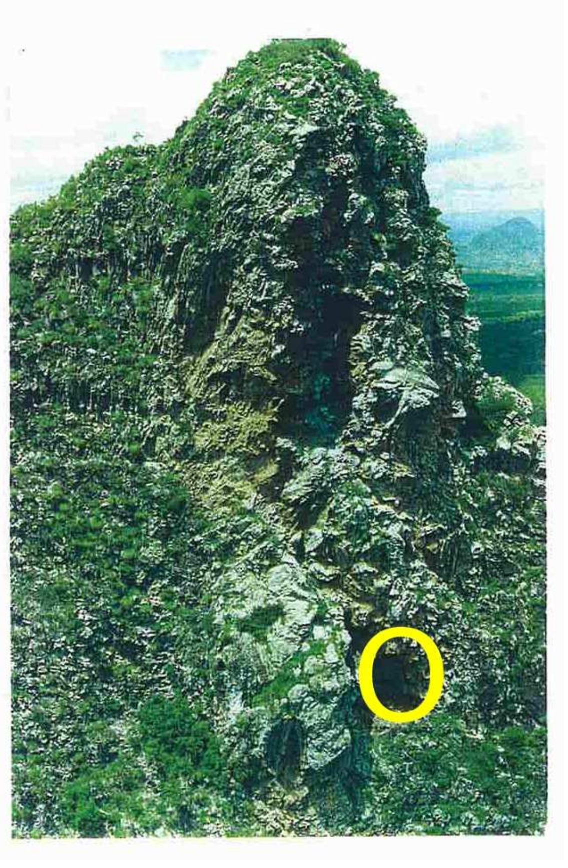

Figure 112. Location of the North face cave ("Mank Master") (image from Coffey (Coonowrin) 1999 [1])

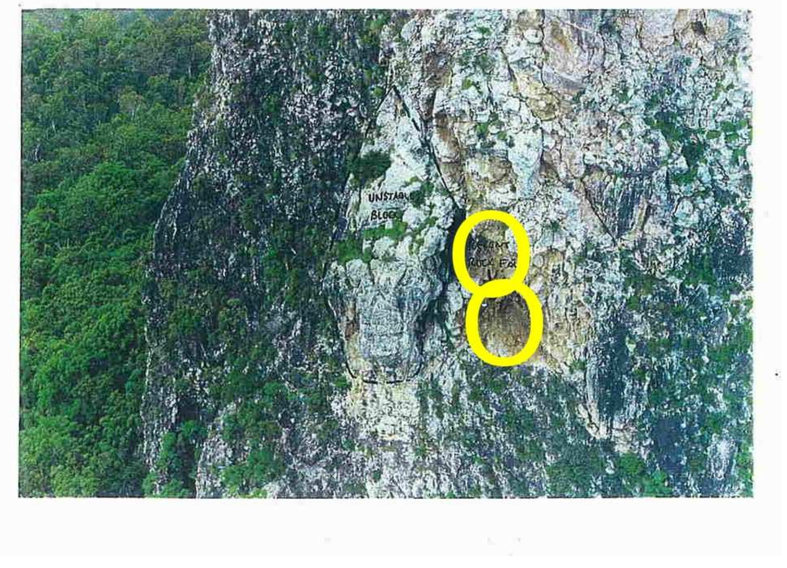

Figure 113. Site examined in this section (image from Coffey (Coonowrin) 1999 [1])

These are some of the location pictures showing the brown mineral crust in this location first hand:

Figure 114. Brown mineralisation

Figure 115. Brown mineralisation

Figure 116. Brown mineralisation

Figure 117. Testing brown mineralisation for adhesion by hand

Figure 118. Testing brown mineralisation for adhesion by hand

Figure 119. Brown mineralisation close up

Figure 120. Brown mineralisation close up

10.2.3.1.3 South East Cave

The brown mineralisation also appears in the cave on the South East corner of the mountain.

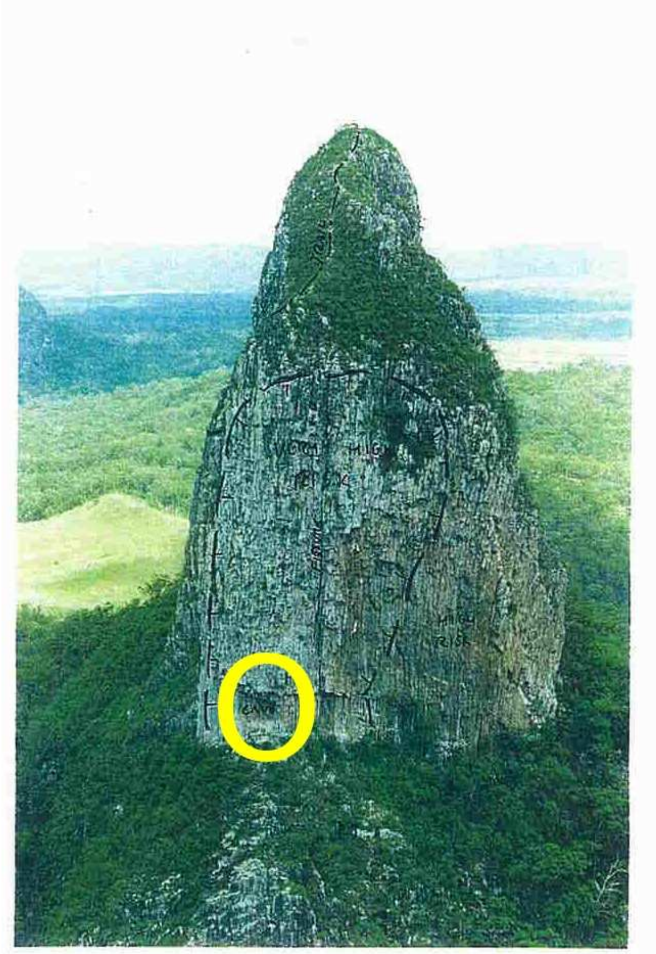

Figure 121. Location of the South East cave (image from Coffey (Coonowrin) 1999 [1])

These are some of the location pictures showing the brown mineral crust in this location first hand:

Figure 122. Brown mineralisation

Figure 123. Testing brown mineralisation for adhesion by hand

Figure 124. Testing brown mineralisation for adhesion by hand

Figure 125. Testing brown mineralisation for adhesion by use of a tool

Figure 126. Brown mineralisation chipped but largely resistant to removal

Figure 127. Brown mineralisation overgrown by aged lichen

The fact that lichen was growing over the brown crust in some places added to the impression that the crust is of significant age.

10.2.3.1.4 South Face Caves

The brown mineralisation also appears in the cave high on the South face of the mountain.

Figure 128. Location of the South face cave (image from Coffey (Coonowrin) 1999 [1])

These are some of the location pictures showing the brown mineral crust in this location first hand:

Figure 129. Brown mineralisation in the South cave

Figure 130. Brown mineralisation

Figure 131. Brown mineralisation

Figure 132. Brown mineralisation

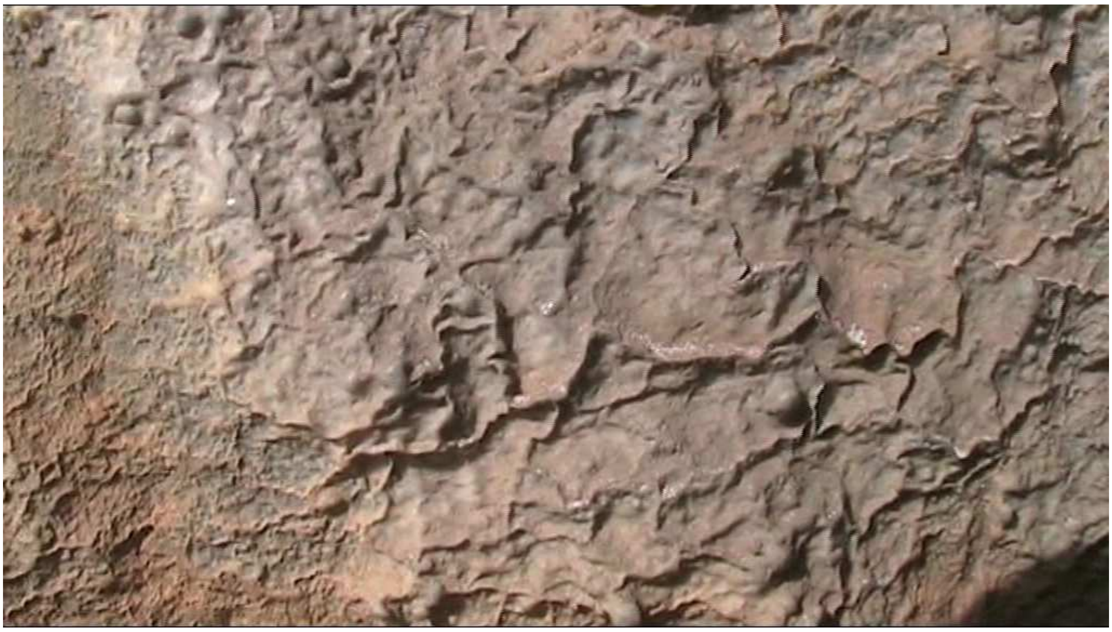

Figure 133. Brown mineralisation close up

Figure 134. Brown mineralisation close up

Figure 135. Brown mineralisation close up

Figure 136. Testing brown mineralisation for adhesion by hand

Figure 137. Brown mineralisation close up

Figure 138. Brown mineralisation close up

Figure 139. Aged inscription found on brown mineralisation in South caves

Figure 140. Name scratched over brown mineralisation, dated 11-12-27 (11 Dec 1927). Aged lichen also growing over the brown crust.

In another location, the following and more examples were found of inscriptions from 1880s to 1920s, confirming the high likelihood of the above inscription being honestly dated. After 1910 this inscription pattern largely ceased, due to the changing patterns of human traffic – the low caves were no longer of interest as the peak had now been climbed and all interest shifted to joining the ascent to the high peak.

Figure 141. Inscription found in another location scratched into brown mineralisation, dated 1-11-15 (1 Nov 1915)

Figure 142. Inscription found in another location written in a durable pencil over brown mineralisation, dated 1899

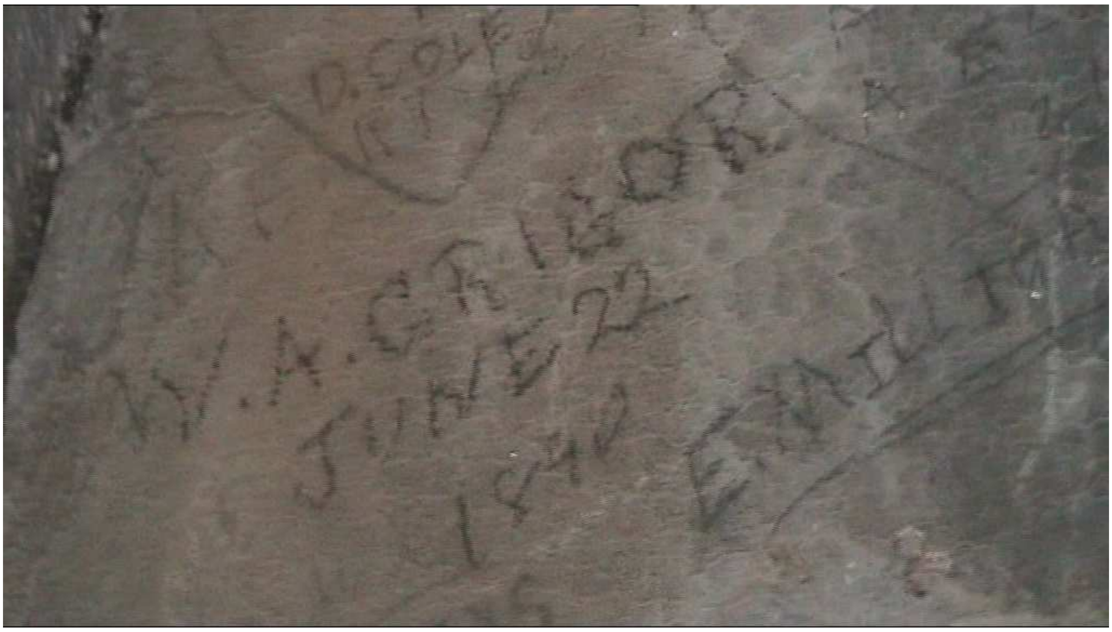

Figure 143. Inscription found in another location written in a durable pencil over brown mineralisation, dated June 22, 1890.

10.2.4 Examination of "Coffey's Block" / Mank Master Cave

Use was made of advanced rock-climbing skills and equipment at the disposal of the research team to ascend into the cave adjacent to the perched block identified by Coffey (Coonowrin) 1999 [1]. In doing so we were able to reach areas inaccessible to the Coffey team and make records of the geological significance of the feature.

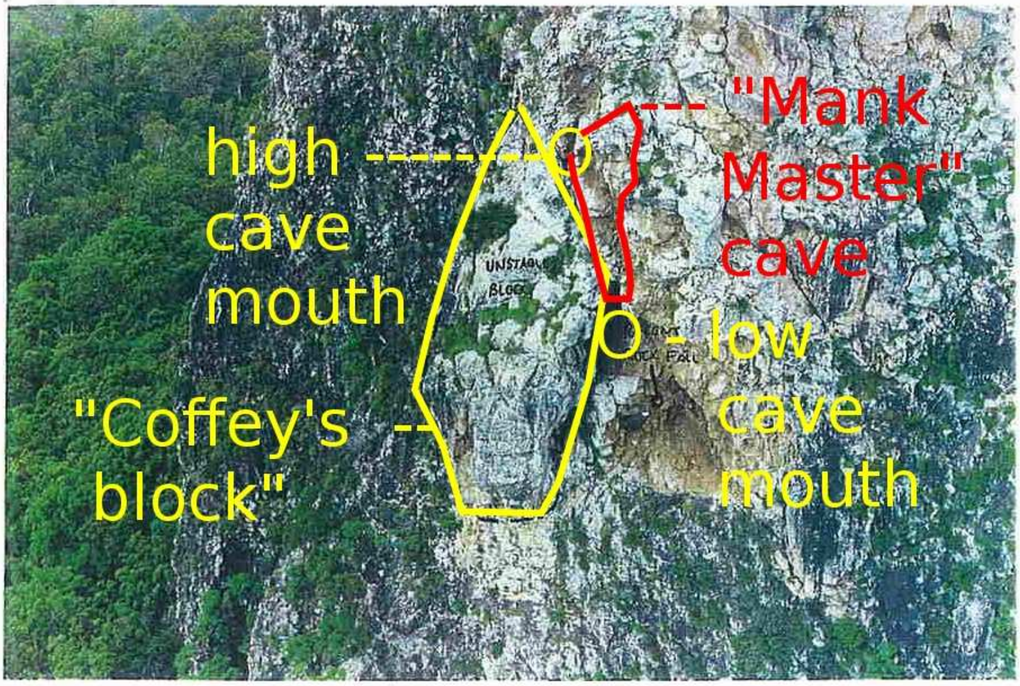

Figure 144. Location of "Coffey's Block" and the North ("Mank Master") cave (image from Coffey (Coonowrin) 1999 [1])

10.2.4.1 External Features

Figure 145. The top of Coffey's block (grey rather than brown) looking from alongside, facing West

Figure 146. The bottom of Coffey's block looking from alongside, facing West (note the camera tilt as given by the horizon)

Notice the slip plane of the block, around the centre left of the photo.

Figure 147. The Eastern face of Coffey's block from below

Notice the slip plane of the block, at the far left of the photo.

Figure 148. The bottom of Coffey's block from below

Notice the slip plane of the block, at the lower left of the photo, on the line of the base of the tree.

10.2.4.2 Internal Structure

Ascent into the cave revealed the following internal features.

Figure 149. Scree and dust inside the floor of the cave

Figure 150. Looking vertically up the cave, from low mouth to high mouth, Coffey's block on the bottom side of the picture

Figure 151. Looking out from inside the top of the cave, Coffey's block on the right side of the picture

Figure 152. Looking out and down from inside the top of the cave, Coffey's block on the right side of the picture

Figure 153. The floor of the upper cave, looking down and outwards

Figure 154. Looking up and out from deeper inside the upper cave, Coffey's block on the right side of the picture

Figure 155. Looking out and down from fully inside the upper cave, Coffey's block on the right side of the picture

Figure 156. Looking directly down from deep inside the upper cave, Coffey's block on the left side of the picture

Figure 157. A rock formation high inside the cave

Figure 158. Crumbly brittle rock

Figure 159. Crumbly brittle rock

Figure 160. Crumbly brittle rock, close up

Figure 161. Hard, mineralised rock with pock marked erosion patterns

The following pictures show the archway of stacked plates of rock. This has been identified by a consulting geologist as a key point of interest to watch for change as an indicator of micro-movement of Coffey's block.

Comparative photos were taken three months apart in 2009, and the feature was unchanged except for the loss of one plate of rock, circled below.

Figure 162. The archway of perched "shale" plates at the top of the rear of the cave

Figure 163. The archway of perched "shale" plates at the top of the rear of the cave

Figure 164 A stress cracking pattern identified to the right of the archway of perched shale plates at the top of the rear of the cave

This cracking feature was singled out by a consulting geologist as being of special significance regarding the stresses being put on this location by Coffey's block. The impression made upon the author by the geologist was that this archway of stacked plates and the stress cracking shown here in them indicates a focal point of the geo-mechanical stress resulting from the restraint of Coffey's block, and monitoring of this feature would be of very high interest in improving understanding of the geo-mechanics in action.

Figure 165. The West side of Coffey's block, high up inside the high mouth of the Mank Master cave

Figure 166. The high mouth of the Mank Master cave, Coffey's block on the right

Figure 167. Outside the upper mouth of the Mank Master cave - Rapidly eroding soft powdery rock, decaying behind a surface of brown mineralisation

Figure 168. Outside the upper mouth of the Mank Master cave - Brown mineral crusted rock to the left, soft eroding powdery rock to the right, in the second upper mouth of the Mank Master cave

Figure 169. Outside the upper mouth of the Mank Master cave - Bands of harder and softer rock eroding in layers, in the second upper mouth of the Mank Master cave

Figure 170. Outside the upper mouth of the Mank Master cave - Bands of harder and softer rock eroding in layers, in the second upper mouth of the Mank Master cave

10.2.4.3 Historic Observations

Another thread of interest was the movement of a large boulder inside the Mank Master cave sometime between 1993 and 1996. During visits in 1993, the author was able to stand and take photographs of his climbing partner from a distance of a few metres across the East-West dimension of the upper cave. On returning around 1996 the cavity had been closed up to being a slot formation less then a metre wide. This was long thought to be a memory or perception failure, however photographs from 1993 were taken to the cave to attempt to reproduce them, so as to do further comparisons of the rock formations over time, and it was found to be impossible to reproduce the original photographer's stance. The East-West dimension inside the cave had indeed closed down from some 2-3 metres to less than a metre.

Attempts to understand the movement of the rock were frustrated by there being no visible boundary of the newly present rock mass impeding the photography stance and the rest of the cave rock surfaces. A break in the continuity of the rock indicating a slip location could not be identified and in fact the formation of the delicately balanced archway of rock plates seemed to defy the concept that any movement had happened in a recent era.

This phenomenon is beyond the author's ability to explain geologically, so I am simply reporting it.

Figure 171. Comparing photographs of 1993 visits to present state

Note the stance of the photographer (the author) in Figure 171 in 1993 is well back, some metres distant from the subject. I recall having no discomfort or imbalance in standing to take those photos in 1993 as well, the cave was broad and inviting in dimension. Our comments at the time were that it was the size and shape of an average bedroom.

Note also the subject in the photo standing high up in a wide cavity, no longer a feature in the cave.

Figure 172 shows the position that I was attempting to find above, and the photographers stance in the photo above was standing on the flat shelf lit brightly in the bottom of this photo, however in 1993 I was standing far to the left in this photo, which is now taken up by the rock mass shown on the left of the photo.

Figure 172. The stance of the 1993 photo comparison, showing the intruding boulder to the left, Coffey's block to the right.

In fact the entire upper cave structure is difficult to reconcile to 1993. The cave seems to run deeper into the mountain than before, although I lack tactile proof of this, and it is now a long high diagonally rising slot shape with difficult stances, rather than a cavitous bedroom shape with easy standing, sitting and even potential lying locations.

10.2.4.4 Examination Summary

My summary of the examination of the Mank Master cave and considerations passed to me by a consulting geologist are that the cave is in fact mobile, and presents an indication of the high geological stress being placed on the mountain by Coffey's block.

The consulting geologist stated that monitoring of this cave would be of high value to understanding the nature of the geological bonding of Coffey's block to the mountain and may provide an indication of the block's final release. Periodic monitoring of the cave is recommended for this reason.

10.2.5 General Mountaineering Understandings of the Slopes

10.2.5.1 West Face Slope

The West face slope is known first hand to the author by virtue of having climbed routes ascending it in the 1990s. It is certainly littered with loose materials in contrast to the rest of the mountain, which is in contrast typically well-bonded at a human level of activity from the perspective of a mountaineer's eye.

Well-known to climbers in the pre-closure period as being hazardous regarding looseness of rock on the slope, it is extremely unattractive as a human-access area, even to climbers. Nevertheless it is traversable using very specialised climbing skills and equipment without dire risks being undertaken.

Ascent of this area was not undertaken during the study, as it requires such particular technical climbing skills, and the comments within Coffey (Coonowrin) 1999 [1] were considered to be parallel to the author's prior knowledge of the face's rockfall characteristics.

From first hand examinations of the past, the West face presents at first hand as being precarious and toppley at a personal level, but likely to stand indefinitely in human timescales, largely as it is. This is similar to numerous other steep rock and earth faces publicly accessible around South East Queensland, such as selected peaks in the Main Range and Border Ranges. Although it's precarious, there is nothing that distinguishes the risks associated with this face from many other equally steep locations in Parks observed at first hand around South East Queensland. It is obviously very steep and many individual stones would be readily loosed if subjected to human traffic, hence only very well prepared people historically go there.

10.2.5.2 North Face Slope

The North face slope (typified by Harry Mikelsen's original path called "The Track" and the route called "Mank Master") has been climbed by the author and others known personally both in the past and during the study. This familiarity is enough to form a general impression of the mobility of the rock from the view of a mountaineer. In general the rock presents as moderately well bonded to human traffic, but must be tested at each individual movement for potential dislodgement. Rock climbers generally regard it as requiring continuous caution.

10.2.5.3 East Face Slope

The East face slope has not been climbed by the author or anyone known personally, however it was very well known to rock climbers historically. It is only ascendable by a fully equipped and specifically-skilled climber. In general the rock presents as very well bonded to human traffic and is generally regarded as trustworthy by rock climbers where previous climbers have already frequently ascended, but requiring vigilant testing where a new surface is explored.

10.2.5.4 South Face Slope

The South face slope has not been climbed by the author or anyone known personally, except for the modern popular track "Salmon's Leap". In general the rock presents as well bonded to human traffic and is generally regarded by rock climbers as trustworthy, but still requiring continuous caution.

11 Key Findings Summary

11.1 Theoretical Rockfall Incidence

The following frequencies and modes of rockfall were derived primarily from Coffey (Coonowrin) 1999 [1], so that this risk analysis is relying on the most authoritative source of information regarding rockfall incidence.

1. Fall of 3 to 4 blocks each of volume 0.5 m^3 per year along the South and East faces.
2. Fall of 1 blocks each of volume 0.5 m^3 per year along the North and West faces. This is an extension of Coffey (Coonowrin) 1999 [1], as this aspect was not treated.
3. Minor landslide of a bulk of earth and/or rock on the North and West faces – volumes ranging from $1m^3$ to 1,500 m^3, using a frequency of "1 fall per 30 years".
4. Major landslide of a bulk of earth and/or rock on the North and West faces – volumes ranging from $1m^3$ to 40,000 m^3 using a frequency of "one per 3160 years".

11.2 Theoretical Risk Levels

The calculations of theoretical risk levels based on Coffey's predictions of rock fall rates gave the following results.

The annualised risk of fatality due to random rock fall confronted by the variety of visitor types historically typical at Coonowrin is in the range of 0.4 per million and 4.3 per million.

It was rumoured that some local residents practised a regular constitutional walk around the area. If so, that visitor type would attract a higher risk due to the greater exposure, calculated to be approximately 40 per million.

These risk levels fall within the safe recommended levels of personal risk under common risk analysis categorisations, including AGS (2007) [6] guidelines.

The risk taken by **local residents** falls within the **"tolerable range" for "existing slopes"**, according to the AGS (2007) [6] guidelines. All the **other modes** of access fall within the **"acceptable" range for "existing slopes"** according to the AGS (2007) [6] guidelines.

It was calculated that there is a 1.35% probability that a fatality would occur due to random rock fall during a single administrative span of 20 years duration, given a resumption of uncontrolled access at 1990's levels of attendance.

11.3 Observed Rockfall Incidence

11.3.1 80 Year Photographic

Photographic comparisons of the cliff faces showed that overall the North, West and East faces are largely unchanged over the 80 year period from 1929 to 2008. There are a few optical mismatches that may indicate some mid-scale rock fall on the north face, but this approximates to an amount within the expectations of the theoretical rockfall quantifications in *Establishing Natural Hazard Mechanisms and Quantities* above.

Of particular significance is the identification of matches in the details of the 1929 rock surface in areas marked in Coffey (Coonowrin) 1999 [1] as “recent rock fall”. This validates a theory that those surfaces have not suffered significant rock fall in the last 80 years at a minimum and therefore the recency of the rock fall must be interpreted as being a geological recency (hundreds to thousands of years, if not much more) rather than recency in a human time scale (years to decades).

11.3.2 Ten Year Photographic

Overall all faces remained largely unchanged over the ten year period from 1999 to 2008. There are a few optical mismatches that may indicate some small-scale rock fall on the West and South faces, but this approximates to an amount well within the expectations of the theoretical rockfall quantifications.

Of particular significance is the identification of matches in the details of the rock surface ten years later in areas marked in Coffey (Coonowrin) 1999 [1] as “very high risk”. This validates a theory that those surfaces have not suffered significant rock fall in the 10 years since Coffey (Coonowrin) 1999 [1], and therefore designation of those areas of the rock surface as “very high risk” does not extend to forming expectations that there will be a high frequency of rock fall from those faces during a typical ten year timeframe.

11.3.3 One Year Photographic

Overall the faces are largely unchanged over the year from 2007 to 2008. There are a few optical mismatches that may indicate some small-scale rock fall on the West and South faces, but this approximates to an amount within the expectations of the theoretical rockfall quantifications.

Of particular significance is that there are few if any verified falls from areas marked in Coffey (Coonowrin) 1999 [1] as “very high risk”. This validates a theory that those surfaces are not suffering from an accelerated rock fall rate, and therefore designation of those areas of the rock surface as “very high risk” does not extend to forming expectations that there will be a high frequency of rock fall from those faces during a typical one year timeframe.

This test predicted it to be most probable that there were 6 to 7 incidents of significant rock fall averaging $0.26m^3$ each off the West and South West faces, when viewed from the West, totalling a volume of 1.72 m^3 during the year.

This test predicted it to be most probable that there were 6 to 7 incidents of significant rock fall averaging $0.32m^3$ each off the South and South West faces, when viewed from the South, totalling a volume of $2.05m^3$ during the year.

The fact that a large number of these observations overlap can support merging these observations to state that around 10 falls were probably observed to have occurred, averaging $0.3m^3$, totalling $3m^3$ per year.

This correlates well to the theoretical fall rate predicted by Coffey (Coonowrin) 1999 [1] of an average rockfall around the peak of 3 to 4 falls per year each of $0.5m^3$, totalling $1.5m^3$ per year

Also of note is the fact that there are very few identified fall sites directly impacting the common walking track route of the 1990s, indicating that the theoretical risk analysis contained here, that assumes a uniform distribution of rock fall, is conservative in this manner; in that less fall candidate sites are observed over the track route and more fall candidate sites are observed over other areas that are not above the track path.

11.3.4 Ground Level Observations

Ground level observations show signs of incidences of recent rock fall as described in *Fallen Rock Around the Skirt* on page 85. Four fall sites were observed over the two-year period. The gross volume ($0.55m^3$) and number (4) of rock fall incidences lies within the range of the expected rate of fall predicted by Coffey (Coonowrin) 1999 [1].

11.4 Examined Key Rockfall Watch Points

11.4.1 Brown Rock

Examination of the brown rock colouration shown in Coffey (Coonowrin) 1999 [1], and noted by that report as “recent rock fall”, indicated that the brown colour is due to the presence of a long-aged mineral crust, rather than a short-aged loose dirt, on the surface. In all cases the age of the rock fall in the location did not seem to have any compelling relationship to the brown rusty mineralisation. Instead, recent rock fall that was identified was dominantly associated rather with the stark white areas of rock, where the rock is eroding in a powdery or “shaley” form.

In some cases this brown mineralisation bore inscriptions from the 1890s-1920s, without indication of any new brown colouration covering the inscriptions, indicating that the minimum age of the brown mineralisation is very hard to interpret as being as short as centuries or millennia, and the age of these faces and the associated rock fall that revealed them must be considered as being much greater than centuries or millennia.

This then shows that the “recent rock fall” indications of Coffey (Coonowrin) 1999 [1] can only relate to a recency in terms of geological eras, rather than in terms of human life-spans, and therefore the calculations of risk take this “recent rock fall” into account as Coffey (Coonowrin) 1999 [1] meaning that it may be indicative of an increased frequency of rockfall geologically (ie: in thousands to millions of years) rather than in human terms (ie: in any few years to centuries).

11.4.2 Coffey’s Block

Examination of the North face cave associated with Coffey’s block found extensive erosion and stress cracking occurring behind Coffey’s block, inside the mountain. During the study a conversation was held with a consultant geologist, and his stated opinion was that the stress cracking occurring in the archway of “shaley” plates in the back of the Mank Master cave behind Coffey’s block was a crucial indication of the mobility of the block - in that the block is perched at a steep angle on a slip plane which is offering it little restraint, and the majority of the weight of the block is being restrained by the bond of the top of the rock into the mountain. This is causing a severe stress on that area of rock high up in the rear of the Mank Master cave, and the result is the stack of shaley and stress cracked plates.

Additionally to this a large movement of rock inside the cave was observed over a time in the 1990s by the author. There is no other verification on hand for this, but it seems incontrovertible. This adds to indication that there is a large geological stress acting inside the upper cave.

The implication is that this block is well-identified by Coffey as being perched on a slip plane, however it is bonded back into the rock of the mountain higher up at which point a great deal of geo-mechanical stress is being exhibited on the rock formations. In a short geological time frame this is likely to break and release the block onto the slip plane alone, which will probably not be able to restrain it. While this is fascinating as a geology subject, it is highly improbable that it will occur as an event in our lifetime, and so it is overrated as a risk to day visitors. The North face is not historically visited in modern terms (1930-1999) by regular visitors, and this area saw only rare human traffic in the 1990s. Even rock-climbing around this face was rare in the 1990s.

Conversely it forms an impending risk should any form of housing or habitable structure be constructed beneath it or in its inevitable path down the earth slope to the floor of the near plain. The probable path of the block may be able to be calculated by a professional geological engineer and all building within that area would be best prohibited.

11.4.3 Chalky Erosion Compromising Pillars

The chalky erosion observed in the caves along the East face was observed to be associated with two of the four rockfall incidences identified. This is in accord with the comments of the consulting geologist mentioned in *Coffey's Block* above. His comments to the author were that, aside from the powdery erosion and stress patterns in the back of the Mank Master cave, the accelerated chalky erosions noted in the East face caves were the only other significant rock fall related patterns that would be of interest in relation to a rock fall risk study.

The caves on the East face are all low to the ground and present very little risk to visitors due to the low height. Chalky erosion may be occurring higher up, but it is not obvious from distant photography. In either case, the East face is not historically visited in modern terms (1930-1999) by regular visitors, and this area saw only occasional human traffic in the 1990s. Rock-climbing around this face was rare but highly valued in the 1990s.

There is some of this chalky erosion in the high cave above the south track ("Salmon's Leap"). In this location it was not as prevalent as the erosion low on the East face, and it seemed to be of a lower order of erosion speed. This warrants continued examination, however the long distance photographs failed to identify high frequencies of falls occurring in this location.

11.5 Advice on Risk Level

In summary, from both theoretical extensions to Coffey (Coonowrin) 1999 [1] estimations of rock fall frequencies and intensive observations on site, the risk to any individual visiting the site falls within common guidelines for personal risk acceptability.

At an accumulated level, the chances that such an event will occur within a typical administration's "watch" is very low, but the reality of the slight possibility must be accounted for by preparing a management strategy including prepared media statements, so that the local rangers are not left to their own resources to make department-impacting statements regarding such an event.

Interest in the location was mostly limited to people with specific skills in the 1990s and prior. It is envisaged that this would be likely to resume given a relaxation of the current restrictions. It is predicted from this analysis that an incident of fatality due to random rock fall is extremely unlikely, and falls below common recommended safety levels. It is expected, regarding the kind of incidents that do arise on these mountains, that a more likely scenario that will arise will be due to personal error, equipment misuse, or just misadventure. These forms of risk have not been analysed in this study and report, and must be regarded as a separate issue.

12 Recommendations

12.1 Preservation

12.1.1 Geological

The location shows little sign of gross alterations occurring over the periods examined.

There was no compelling evidence discovered that there is currently an unexpectedly accelerated rock fall rate, beyond that predicted by Coffey (Coonowrin) 1999 [1].

The rock feature described as Coffey's block and the Mank Master cave are potentially vulnerable to more rapid change than the rest of the location. These features warrant significant continued study to continue monitoring and increase understanding of their geological nature. It is possible that Coffey's block could be prematurely dislodged by a major earth tremor, and any such event occurring artificially should be absolutely avoided in the interests of preserving this iconic natural feature. This has particular implications for the local quarrying operation, and in the past the Department of Mines is reputed to have proven that this is not a risk. This was not validated in this report and is merely reported for thoroughness.

12.1.2 Botanical/Biological

During the period since access restrictions were introduced, the area has exhibited little substantial change in plant and animal life. Vigorous insect infestations were observed on the peak a number of times, flowers were in bloom in spring, and bats and birds inhabit various locations around the site.

The original walking track line appeared to be little overgrown since 1999. Above the cliff base it was slightly obscured such as to require attention to detail to avoid heightened risk of error.

12.2 Presentation

There was little found in this study that validates continued restricted access, and the findings imply the converse: that the area does not require a restricted access status on the grounds of random rock fall. The area may be manageable by a number of strategic options, and it falls in the domain of the land manager in consultation with the public to ascertain an appropriate form of presentation.

The following two forms of access are noted for convenience, as they are the most prominent options currently in common use.

12.2.1 Special Access

It is possible to envisage that access permits can be issued to anyone who applies for such at present, without a requirement to qualify the applicant's activity or skills. It would be advisable to provide any permit holder with a statement of the known risks in the area in advance of their access, and require an acknowledgement of risk acceptance – the visitor's personal acceptance of those and other unstated but common wilderness risks as being undertaken at their responsibility.

12.2.2 General Access

Given the findings of this study, there is no clear reason not to simply remove the current access restriction and permit general access, leaving the public to self-regulate their safety as is the practice on all other areas of the Glasshouse Mountains National Park. This would return the location to being in line with land management in the rest of the area and removes the need to manage the area by exceptional rules.

The management practices currently established at Beerwah and Tibrogargan, of warning signage and specific area closure during identified landslip events, seem to be warranted.