In the Dark Shadow of the Supercycle
Tailings Failure Risk & Public Liability Reach All Time Highs

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1.0 SUMMARY

In the shadow of the "supercycle",[1] and propelled by its dysfunctional economic dynamics, risk and public liability from mine tailings storage facility (TSF) failures reached all-time highs. The annual failure rate for significant TSF events escalated from a 50-year average of 0.56 "Very Serious"[2] TSF failures per year (33/50) to 1.0 (10/10) for the period of price run up 2000-2010 as described by the HHWI (Rossen 2015), a 78% increase. In this period, copper prices steadily climbed reaching an all-time post war[33] high of $9411 per tonne ($2015) in 2011 as compared to the prior 50 year average price of $5133. These facts challenge the widely held notion that failures are mainly shaped by falling prices. They point to more fundamental and still not fully examined or understood root causes of TSF failures. What is apparent in the forensic record is that the increasing severity and frequency of high consequence failures reflects in part an aging infrastructure at depleted mines which are no longer economically viable even at record high prices. There are also indications that many were never viable and were just abetted into existence through venture capital on loosely regulated exchanges or advanced on faulty feasibility studies.

The 78% increase in failure frequency and severity which occurred during the price run up of the present "supercycle" challenges the widely held notion that failures are a response to tightening economic conditions (falling prices) and points to more fundamental and still not fully examined or understood root causes of tailings storage facility failures.

What seems apparent and even widely understood within the industry, though not yet widely acknowledged, is that we have reached the outer limit of the mining industry's long standing metric that ever lower grades of ores can be mined through "economies of scale". A close examination of the data

[1] Supercycle refers to a multi-year period of sustained price increases in commodities and raw materials.
[2] We define "Very Serious" TSF failures as those involving a release of 1 million cubic meters or more
[3] The all-time annual average high since 1896 was 1916 at $13,572 ($2015) followed by 1917 at $11,876

seems to show that the "mining metric"[4] stopped working sometime in the mid 90's. It is from this turning point in the efficacy of the mining metric that conditions which evolve to catastrophic failure began forming, incubating and progressing. During the supercycle as prices climbed to all-time post war highs, grades, even at major producing large mines, dropped to all-time lows. Meanwhile, post supercycle, mines still premised on this economies of scale model continue to be put forward with unverifiable claims of economic viability, or with no demonstrated reasonable expectation of full compliance with external environmental and other community protective standards.

Post Mt. Polley, and now post Fundão, none of the much publicized government and industry studies and reforms address any of the key root causes of high severity high consequence tailings failures or commit to any changes in law and policy that will be effective in preventing the man-made losses.

The data increasingly dictate that we need a completely new approach to navigate this new era of mining. We need action to identify and correct already accrued public liability the end of this era has left behind in standing operating TSFs. This can only be accomplished through the application of comprehensive law and policy addressed to these two imperatives. The fragmented legal frameworks for mining in most prevalent use today globally have conclusively demonstrated their failure to adequately protect the public interest. Post Mt. Polley, and now post Fundão, none of the much publicized government and industry studies and reforms address the key root causes of high severity high consequence tailings failures or commit to any changes in law and policy that will be effective in preventing man made losses in existing, not yet closed marginal mines.

This paper endeavors to make that case forensically with global failures data 1916-2015 (Chambers-Bowker) in the context of assessments by leading mining analysts including Deloitte (2013), McKinsey (2015), Aguirregabiria & Luengo (2016), Ernst & Young (2015), and Price Waterhouse (PWC 2016).

Remains of Bento Rodriguez after failure of Samarco's Fundao tailings dam.

[4] The "mining metric" is higher mine production necessitated by lower grades of ore, a century of declining prices offset by declining costs per ton. The metric is to continuously develop the resource through economies of scale, larger and deeper footprints, more efficient operations, bigger and better bulk mining technology.

2.0 THE CO-ENTANGLEMENT OF SUPERCYCLE ECONOMICS & TSF FAILURES

It is irrefutable that the frequency and consequence of Very Serious Failures and of Serious[5] Failures is continuing to increase at alarming rates, that the trend emerged and grew post 1990 and that it is in large part a consequence of conscious decisions made at the mine-level to make up for fundamental mine and miner specific economic disadvantages viz. global economics. Short cuts on waste management, especially of tailings management, were and are a fast, easy, under the radar way to try to meet the high production volumes and low cash costs investors insist on (Bowker & Chambers 2015, Bowker & Chambers 2016). The dysfunctional, reactive economics of the supercycle are expertly analyzed and well characterized by Deloitte in their 2014 market trend analysis. "*In their relentless pursuit of growth in response to pressure from investors and analysts, companies developed massive project pipelines. Some also developed marginal mines, hoping commodity prices would buoy poor project economics. In their headlong pursuit of volume, many mining companies abandoned their focus on business fundamentals. They compromised capital allocation decision making in the belief that strong commodity prices would compensate for weak business practices. Rather than maintaining a long-term view of the market, many acted opportunistically.*" (Deloitte 2013).

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Price Waterhouse Coopers, looking at the performance of the top 40 over the supercycle, note that much of the massive commitment of capital to expansion and production at any cost ended up as impairment write offs: "… *from 2010-2015, the top 40 have impaired the equivalent of a staggering 32% of the capex incurred*". They note that $36 billion, or 68 % of the total impairments, were taken by Glencore, Freeport Vale and Anglo American and that "*2015 saw the first widescale mothballing of marginal projects*". The top 40 took a collective net loss of $27 billion and investors punished them for "squandering the benefits of boom" and for "poor capital management and investment decisions". (PWC 2016).

It is in this dysfunctional "maximum production at any cost" dynamic of the supercycle that we see a dramatic upturn in the frequency and severity of failures, and in which there is with very little doubt a higher global portfolio risk of accrued and unexamined public liability. As presented in Section 3, below, changes in waste rock to metals ratios for gold suggest the possibility of a more than 100% increase in the level of potential unexamined risk (SRSrocco 2016).

Immediately following we describe the degree of consequence and severity that the supercycle has directly caused and present the evidence that before the supercycle even began, the mining metric of economies of scale had begun to come unraveled and the consequence of that manifest in the early appearance of the high severity failure trend.

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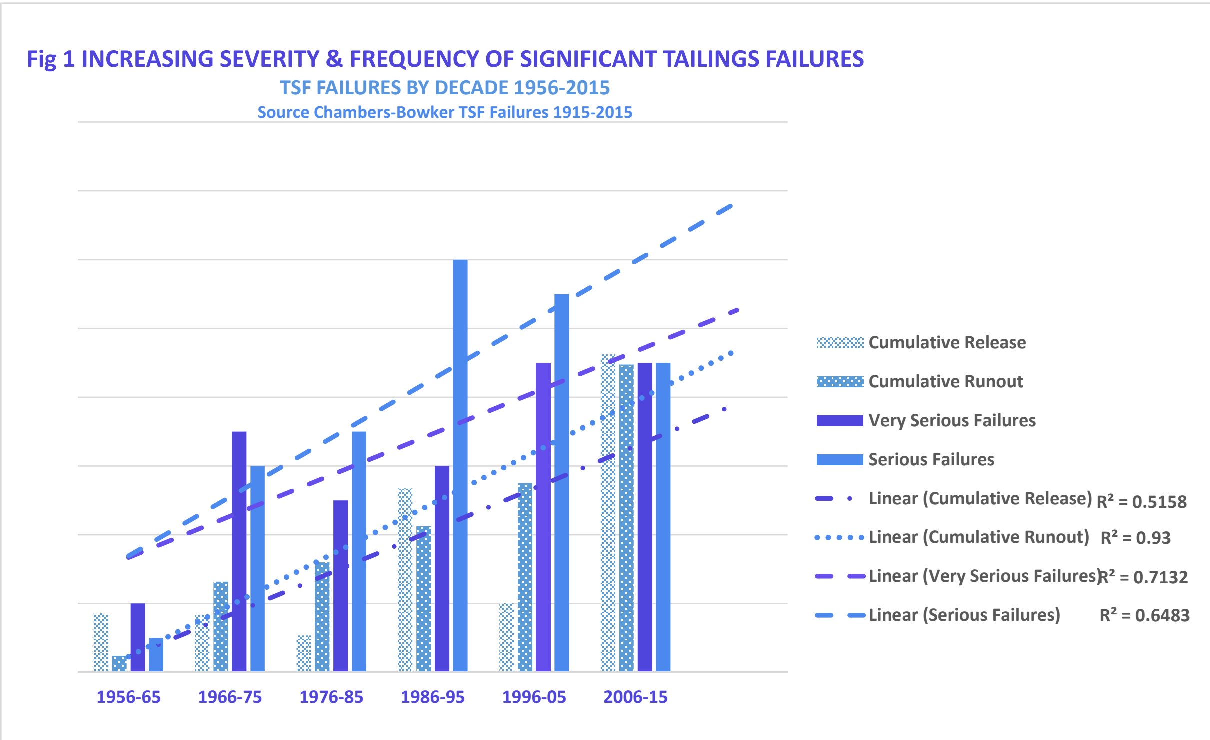
[5] We define "Serious" TSF failures as those with a release of greater than 100,000 m^3, but less than 1 million m^3.

3.0 DIMENSIONS OF THE SUPERCYCLE'S IMPACT ON TAILINGS FAILURE TRENDS

As graphically illustrated in Figure 1, below. The absolute number of major failures, and the severity of all failures as indicated by cumulative release, and cumulative runout per decade has steadily escalated reaching all new highs. (The present decade (2006-2015) captures the steepest part of the price run up of the Supercycle and just the beginning of the steep and sudden downward leg.) It is important to note



that the escalation of severity as measured in release volumes and run out distance for all recorded events is nearly parallel with the slope of the trend lines of both Serious and Very Serious failures. That is, the overall magnitude of all significant events is increasing and affecting ever larger surrounding areas.

TABLE 1 ANTICIPATED INCREASES IN FREQUENCY & SEVERITY 2016-2025

Time Period	Very Serious >1M m3	Serious >100k m3	Cumulative Release M m3	Cumulative Run Out km
2006-2015 (actual)	9	9	895	92
2016-2025 (predicted)	15	15	937	110
Projected % change	+67%	+67%	+5%	+8%

Estimating major failures by proven actuarial methods (Bowker & Chambers 2015) and projecting cumulative runout and release by trend line, the overall severity profile for the coming decade, 2016-2025 (Table 1), will be 67% higher for both major failure categories and severity will reach all-time highs with more modest projected increases of 5% and 8% respectively.

Although not statistically significant by normal standards of minimum observation size, the fit to a linear trend line and the strong r-square values for both Serious and Very Serious failures and for the two severity elements shown in Figure 1 above completes the compelling and persuasive forensic evidence of increasing frequency and severity of TSF failures.

The data set on all 290 events in the failures data base is shown in Table 2 below with predictions for 2010-2020 and for 2016-2025 on a per million tonnes of Cu ore production basis. The 2010-2020 projection has increased from 11 to 13 based on the additional 5 years of failures and substantially more complete information on pre 2010 failures. Predictions for 2016-2025 are 15 for both high severity categories, an annual rate 67% higher than the 2006-2015 decade.

TABLE 2 TSF RELATED FAILURES & EVENTS BY SEVERITY 1906-2015

Decade	Dam Failures "Significant Events"			"Other Events"		Total
	Very Serious	Serious	Other	Non-Fail	Non-Dam	
1906-15	0	1	0	0	0	1
1916-25	0	0	1	0	0	1
1926-35	1	0	0	0	0	1
1936-45	1	0	7	0	0	8
1946-55	1	1	5	0	0	7
1956-65	3	1	30	0	1	35
1966-75	7	6	37	0	4	54
1976-85	5	7	36	2	2	52
1986-95	6	13	34	3	0	56
1996-05	9	11	17	0	0	37
2006-15	9	9	16	3	1	38
	=======	=======	=======	=======	=======	=======
Occurred	42	49	183	8	8	290
pred 2010-20	13	13	n/av	n/av	n/av	n/av
pred 2016-25	15	15	n/av	n/av	n/av	n/av

4.0 ROOT CAUSES OF FAILURE BEYOND PROXIMATE CAUSE

Virtually all Very Serious Failures in recorded history were preventable, either by better design or by better operational management. It is widely recognized now that "proximate cause"[6] of failure is not a matter of force majeure, unforeseeable and uncontrollable events, "black swans"[7], or ordinary human error, but a result of conscious decisions at odds with Best Practice, Best Knowledge and Best Available Technologies. Of course, the proximate cause of all TSF dam failures is geophysical and structural in nature, but the *root cause* is a failure to design, build and manage TSFs to known Best Practice, Best

[6] Proximate cause in insurance is defined as an event sufficiently related to a legally recognizable injury or loss to be held to be the cause of that injury. Here we mean looking at the precipitating final physical cause of a major failure

[7] A "black swan" is a high severity loss that results from the cumulative effect of a large number of small, unforeseeable, unpredictable events or conditions.

Knowledge, and Best Available Technology. Though few put it in these plain terms, the Mt Polley Expert Panel was very clear.

In Brazil and in British Columbia, professional practice and regulatory guidance allowed unrestrained reliance on "observational method"[8] as circmstances beyond TSF design requirements and assumptions arose.

It is widely recognized now that proximate cause of failure is not a matter of force majeure, unforeseeable and uncontrollable events, "black swans", or ordinary human error. The almost universal conclusion of all dam failure analysis focused on proximate cause is a failure to apply and adhere to known best practice and best knowledge.

The Fundão dam had serious construction flaws in the base drain and filters, concrete decant galleries were structurally deficient, operational deviations allowed structurally weak slimes to be deposited in areas where they were prohibited by the operating plan, and the dam crest was moved and constructed over these slimes causing the dam failure (Fundão Review Panel 2016).

At Mt Polley, the miner deviated from the construction design, and the review committee found the dam would not have failed if the original design had been followed, despite the undiscovered lacustrine layer (Mt Polley Expert Panel 2015).

All of the earthquake triggered failures in Chile in the 1960s were found to be associated with the prevalent use of upstream construction for TSFs in an area known to be prone to frequent, high severity earthquakes (Villavicencio et al. 2014).

With the exception of recent updates to law and policy in Australia (West Australia ,South Australia, and New South Wales), we are not aware of any other legal framework for mining that enforces a primary Best Practice/Best Available Technologies performance standard life of mine. Regulatory agencies defer to industry; do not formally adopt existing guidelines like MEND or ANCOLD (2012); and, largely depend on their own or consulting engineers without independent review to make key decisions affecting risk and viability. As the Mt Polley Expert Panel noted, the standard applied in this prevailing framework often puts economic exigencies and production schedules ahead of the public interest.

This focus on proximate cause in the autopsy of catastrophic events on the one hand and the determined avoidance of BAT or Best knowledge in law and policy sets up a dynamic where it's easy to look to short cuts on all aspects of mine waste management practice without raising any concerns on the part of regulators or investors.

It is widely acknowledged even by the industry and major industry trade groups that Best Knowledge and Best Practice and Best Available Technology will not be universally

[8] The observational method is a field response to changed conditions or conditions different from expected without study or systematic analysis. The Mt Polley Report notes "The Observational Method … relies on recognition of the potential failure modes, an acceptable design to deal with them, and practical contingency plans to execute in the event observations lead to conditions that require mitigation. The lack of recognition of the critical undrained failure mode that prevailed reduced the Observational Method to mere trial and error."

applied without a legal mandate. Neither MAC (2015) nor ICMM (2016) have adopted such standards as mandates for their members. The British Columbia Ministry of Energy and Mines (BC MEM) response to the Mt Polley Expert Panel recommendations avoided several of the main recommendations of the Mt Polley Expert Panel to the point where BC MEM requirements will not adequately protect tailings dams from future failures (Chambers 2015).

The focus only on proximate cause in the autopsy of catastrophic events on the one hand, and the determined avoidance of Best Available Technology, Best Knowledge and Best Practice in law and policy on the other, sets up a system wherein it's easy to look to short cuts on all aspects of waste management practice without raising any concerns on the part of regulators or investors. (To BC MOM's credit, they did flag the exact location of failure two years before and did press for a full buttress which was resisted and contested.) (Mt Polley Expert Panel 2015).

More importantly, the focus on proximate cause fails to address or understand the more fundamental root causes that result in these deviations where law does not require and enforce adherence to the application of best practices in all phases of TSF design, construction, operation, and closure, or to require expert independent review of key decisions affecting public risk and economic viability.

4.1 The Root Cause of Inherent Economic Weakness at the Mine-level

A recent study of actual annual mine records of 330 mines comprising 85% of world copper production sheds some light on the economics that may apply for all metals, and may hold keys to a deeper understanding of the relevant economic red flags of possibly incubating failure conditions (Aguirregabiria & Luengo 2015). The study reports that on average only 52% of mines were active at any time in their study period, 1993-2010 (173/330) and that 32% produced no mined output at all during the supercycle (maximum active was 226). This suggests the possibility that from 30% to 52% of all "still open" copper mines globally may not be economically feasible and cannot be expected to generate revenue sufficient to cover production costs. In many instances perhaps mines should never have been developed in the first place. Certainly no one would dispute that there are many mines that have never been profitable and that have frequently been in and out of production due to price sensitivity.

.. only 52% of "operating" {copper} mines were active 1993-2010 (173/330) ; 32% produced no mined output at all during the Supercycle. This suggests the possibility that from 30% to 45% of all "still open" copper mines globally may not be economically feasible In many instances perhaps many of these mines should never have been developed in the first place.

As Figure 2, based on the Aguirregabiria & Luengo (2015) report shows, in the run up of the supercycle the active participation among the 330 mines swelled from 144(44%) to 226(68%) (viz. an average of 173 active at any one time). It is in this increased re-entry, and often expansion of economically fragile mines (also see PWC 2016) that the trend to ever increasing severity and frequency of catastrophic TSF failures has manifested.

FIGURE 2 NUMBER Of PRODUCING RE ENTRANTS INCREASES WITH PRICE

SOURCES USGS(2014) AGUIRREGABIRIA-LUENGO (2016)

It is generally recognized within the industry that a widespread "cleansing" is both needed and well underway post supercycle metals price peak in 2011. Regulators meanwhile continue to avoid enforcement and duck corrections at these marginal mines hoping for a return of prices that will allow problems to be addressed out of mine revenues that are not likely to ever come again. They fear that enforcement actions may trigger bankruptcy, as occurred at the short-lived re opening of the Yellow Giant Mine. Government is not treating the widespread shedding of these marginal mines as possibly separating the deeper pockets who tried to force production out of these mines from the liabilities that may have accrued.

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As no known regulatory authority keeps a publicly accessible inventory of TSFs or TSF "significant events," it isn't possible to identify which of these re-entries and expansions in the supercycle are those in the failures data base. However, Mt Polley was definitely one of these, reopening in 2005 after a 4-year standby following a brief and unprofitable prior period of operation. Forensically, if not statistically, it is strongly suggested in the case records and histories that weak economics is common among failed mines. Further, it has been possible to persuasively map the connection between significant failure events and global mine economics (Bowker & Chambers 2015, Bowker & Chambers 2016), and these relationships in turn point to characteristics at the mine-level that are likely indicators of failure risk underlying what ultimately becomes the proximate cause of failure, the last event in the chain manifesting as physical failure.

4.2 The Directly Measureable Relationship between Failure Trends & Global Mine Economics

The global economic history of metallic mining is best and most frequently described with four key variables: (1) volume of metals produced from mines, (2) realized price for that volume, (3) costs to produce, and (4) grade of ore to the mill. Over the past 100 years, the key dynamic of metallic metal mining globally for all metals has been declining grades and declining prices punctuated by a few short term supercycles. As grades fell across all metals for discoveries, reserves and head grades, economic feasibility and the possibility of profit has turned mainly on the economics of ore production made possible through open pit mining. The cost to move a tonne of ore from the ground to the mill is completely independent of grade and of the ultimate price that will result.

This brings two additional key variables into play as the background economics that result in high failure frequency and severity: (1) ore production volume, and (2) the mining cost per tonne of ore.

Mine economist Richard Schodde (Schodde 2010) correctly mapped the major historic role the unit cost of ore production has played in holding the line against falling grades, and against the long term decline in prices. He calculated that while overall mine costs (C1), 1900-2010 had declined by 50% in real dollars, that when distributed over ore volume, the per-tonne of ore production cost had declined 87%. This is what made the mining metric workable and profitable for some but not all. Schodde argued that the decline in ore production costs would continue to "grow the resource" even as grades continued to fall (discovery, reserves and as milled). What the World Bank detected was the dramatically widening gap between ore production volumes and mined metals output (World Bank 2006).

This gap could also be described as declining yields on the economics side and exponential growth in wastes on the environmental side. In only 8 years from 2005 to 2013 the decline in yields for gold was 29%, from 1.68 g/t in 2005 to 1.20 g/t in 2013. On a waste rock to metals basis that translates to a 117% increase from 52 tonnes/oz to 113 tonnes/oz (SRSrocco 2014). It is to this gap of ever declining yields, and its relationship to the emerging trends of catastrophic failures that prior research (Bowker & Chambers 2015, Bowker & Chambers 2016) and this paper are addressed.

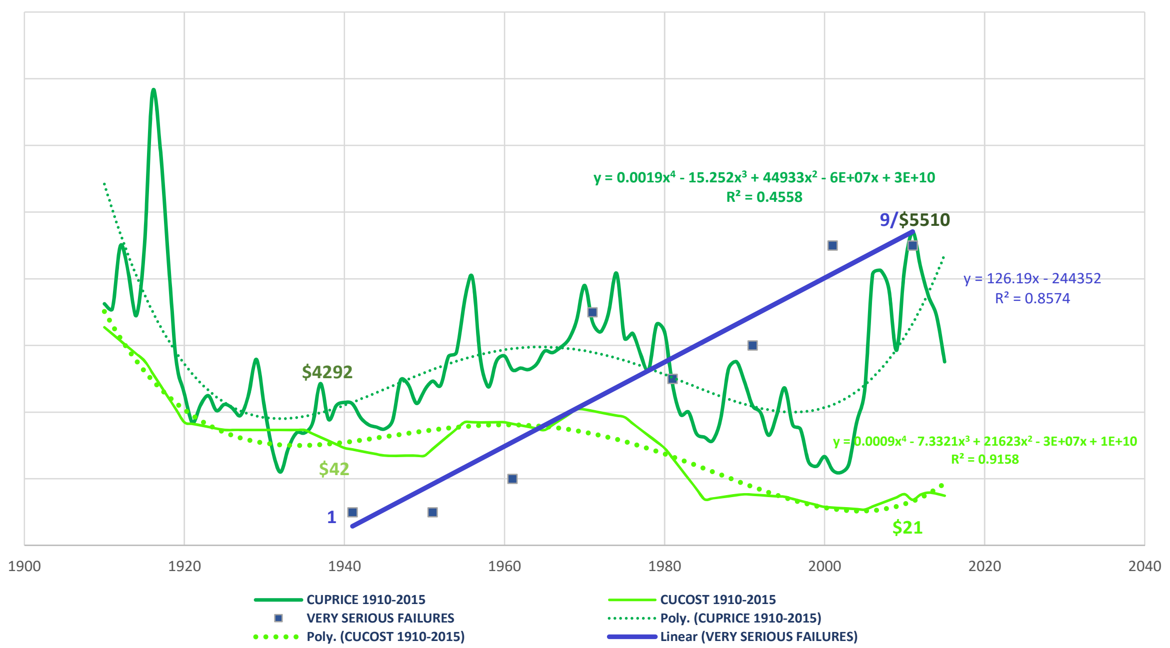
***In only 8 years from 2005 to 2013 the decline in yields for gold was 29%, which on a waste rock to metals basis translates to a 117% increase from 52 tonnes/oz to 113 tonnes/oz**. (SRSrocco 2014)*

The previously established correlations between failure severity and these five key mining economics parameters (Cu Ore, Cu Grade, Cu Metal, Cu Cost, Cu Price) is reaffirmed in failures and mine economics data as of December 31, 2015, as shown in Table 3, below.

Table 3 CHANGES IN CORRELATIONS 1940-2009 As Known July 2015 v As Known July 2016					
DATE/SEVERITY	VERY SERIOUS	SERIOUS	CUORE	CUGRADE	CUCOST
Ver Ser Jul'15	1	0.880	0.860	-0.794	-0.788
Ver Ser Jul'16	1	0.903	0.953	-0.825	-0.754
Serious Jul'15	0.880	1	0.720	-0.884	-0.682
Serious Jul'16	0.903	1	0.824	-0.843	-0.801
Sources: Bowker Mining Economics 2016 Chambers-Bowker TSF Failures 1915-2015					

What emerges with more complete data on pre-2010 failures than we had in July 2015 and the additional six years of data (2010-2015) is an interesting, new view of the relative strength of correlations in the two high severity failure categories. Ore production is reaffirmed as the most dominant but with much higher correlations with both severity categories, 0.953 for very serious and 0.824 for Serious. Grade clearly emerges as much more dominant for Very Serious Failures and copper production cost (CUCOST) emerges as much less important for Very Serious Failures and much more important for Serious Failures. Overall there is more clarity on Serious Failures, and it is now apparent they are shaped by the same forces as Very Serious Failures.

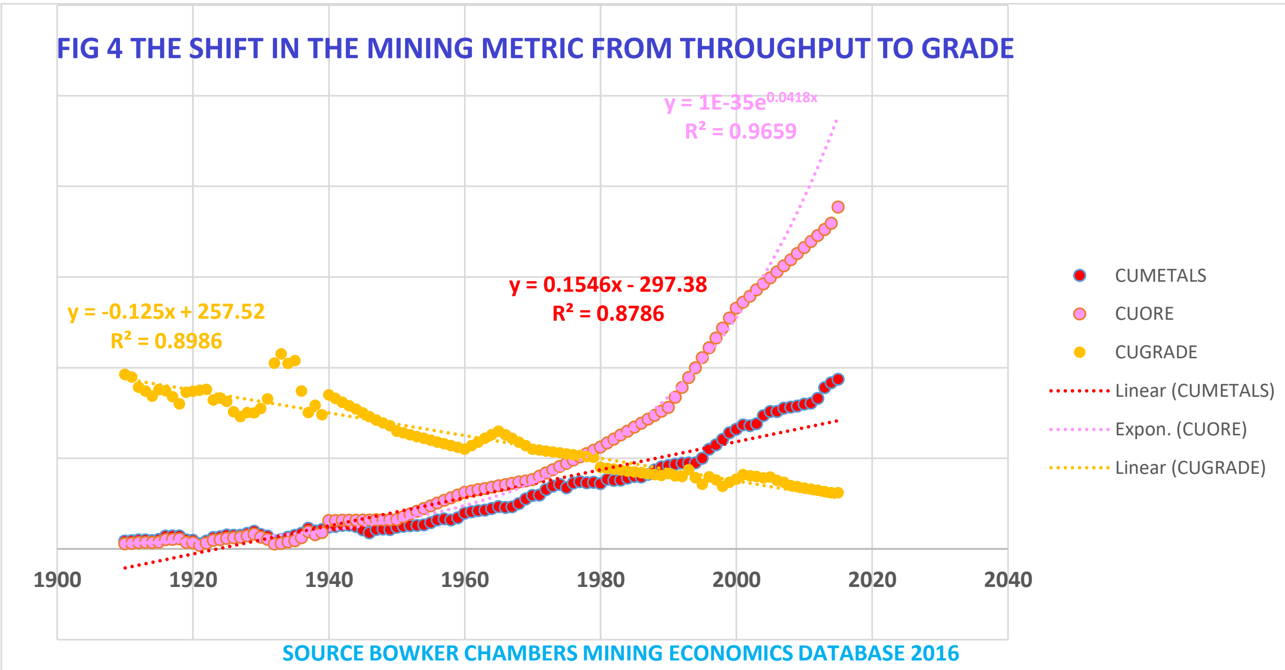
FIG 3 FAILURE TREND INCREASES DESPITE LOWER ORE PRODUCTION COSTS & EXPONENTIAL PRICE RISES



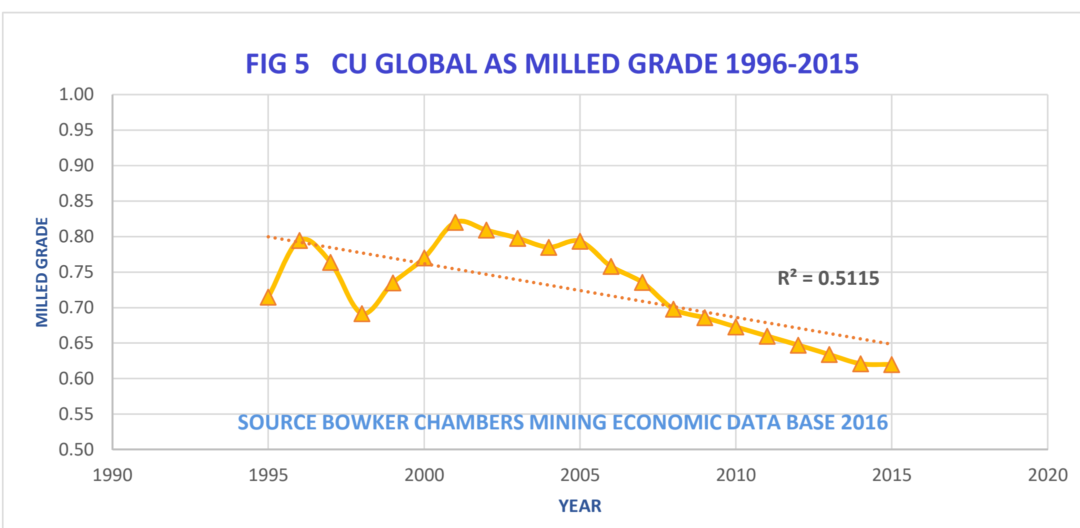
SOURCES: BOWKER CHAMBERS MINE ECONOMICS DATA BASE 2016, CHAMBERS BOWKER TSF FAILURES 1915-2015

As is clear in Figure 3, below the rising trend of Very Serious Failures emerges despite the long term offsetting effects of lower ore production unit costs that accompany the plunge in as-milled grades.

The World Bank noted this shift in the relationship between finished metals production and ore production as of 2000 (World Bank 2006). As we previously mapped, that spread continued to widen through 2009 (Bowker & Chambers 2015). In the 6 years since 2009 the spread is even more pronounced primarily as a result of an even steeper and faster decline in available ore grades that the industry neither foresaw nor prepared for. This increasing spread between metals production from mines and ore production needed to attain that level of production very clearly begins around 1990, almost a full decade before the start of the supercycle. (See Fig 4 below) A closer look at what was happening to grades (Fig 5) as prices rose over the supercycle reveals the key impetus for failure.



Over the entire period of the supercycle, as shown in Figure 5, "as milled" grades have dropped significantly, affecting not only smaller economically marginal mines but the behemoth Chilean and Top-40 producers as well.



As devised by ICOLD (ICOLD/UNEP 2001) and carried on by WISE (WISE 2016), the tailings dam failures data base captures no data on geological, geochemical or econometric descriptors of the mines with failed TSFs. The data on physical characteristics of the TSF facility (height, capacity, type of construction) and severity (run out release deaths) is sporadically reported, even for catastrophic failures. We have nevertheless been able to piece together some mine-level econometric markers on some of the mines with Very Serious Failures post 1990. The data on 7 of 18 mines with Very Serious Failures post 1996 strongly indicate that the econometric markers of these mines are significantly below global averages.

Average reserve grade as of failure for the 6 mines which are primarily copper producers was 0.37 as compared with a global average head grade at producing copper mines of 0.76. Of 7 mines with Very Serious Failures 1992-2010 the Cu equivalent grade (i.e. taking account of other metals produced or translating all metals into Cu equivalent) was 1.10 as compared to a "realized grade" of 2.25 reported by Aguirregabiria & Luengo (2015) for their 330 producing copper mines. These are imperfect and non-exact comparisons but they are also strongly persuasive that mines which produce Very Serious TSF Failures are poor performers viz. average global econometrics. This in turn suggests a significant public interest in giving independent authoritatively verified economic feasibility a specific and prominent place in mine and mine expansion approval, and in life-of-mine and life-of-facility regulatory oversight.

Data on 7 of 18 mines with very serious failures post 1996 strongly indicate that the econometric markers are significantly below global averages. At those which are primarily copper mines average reserve grade at failure was 0.37 as compared with a global average head grade at producing mines of 0.76. Of mines with very serious failures 1992-2010 the realized grade taking account of all metals was 1.10 as compared to 2.25 for all copper mines.

These adverse grade deviations at the mine-level translate to, and are determinant of, higher costs to produce, as well as of larger waste volumes per unit of metal produced.

The fundamentals of how this plays at the mine-level is simply and succinctly expressed by Andrey Dashkov, Senior Analyst, Casey Research**:** "As a project moves to the development stage, the higher the grade, the more robust the projected economics of a project. For a mine in production, the higher the grade, the more technical sins and price fluctuations it can survive." (Dashkov 2013). Continuing in this analysis Dashkov goes on to declare that volume and throughput (the Scholz foundation for profitability of low grade mines) is "no longer king," and that grade is "now king" in determining which mines will be successful and which will fail. This was essentially validated by Bowker & Chambers (2015) as the context and main driver in the emerging prevalence of catastrophic failures.

As a project moves to the development stage, the higher the grade, the more robust the projected economics of a project. And for a mine in production, the higher the grade, the more technical sins and price fluctuations it can survive." (Dashkov 2013). Continuing in this analysis Dashkov goes on to declare that volume and throughput (the Scholz foundation for profitability of low grade mines) is "no longer king," and that grade is "now king" in determining which mines will be successful and which will fail.

Dashkov's analysis is that a grade advantage is a critical determinant of ability to survive serious technical flubs and dramatic unpredictable price fluctuations. As a norm for all metals, this means that smaller, lower grade mines will suffer more and have more physical manifestations of their economic stress than larger, higher grade mines. Very simply, smaller, lower grade mines operated by junior and midsize miners have less cushion. They have to ride too close to the edge of financial viability viz. global metals markets and major producers to try to stay in production. They also have less access to high quality capital markets, paying more and operating under more onerous terms of credit than the top producers. This is a factor that George Ireland has frequently cited as creating financial instability and uncertainty, when the due dates of credit don't match up with cash flow needs, expected revenue generation, and production capacities of the mine. This mismatch can actually lead to failure or involuntary investor takeover elevating uncertainty and instability (Sylvester 2012).

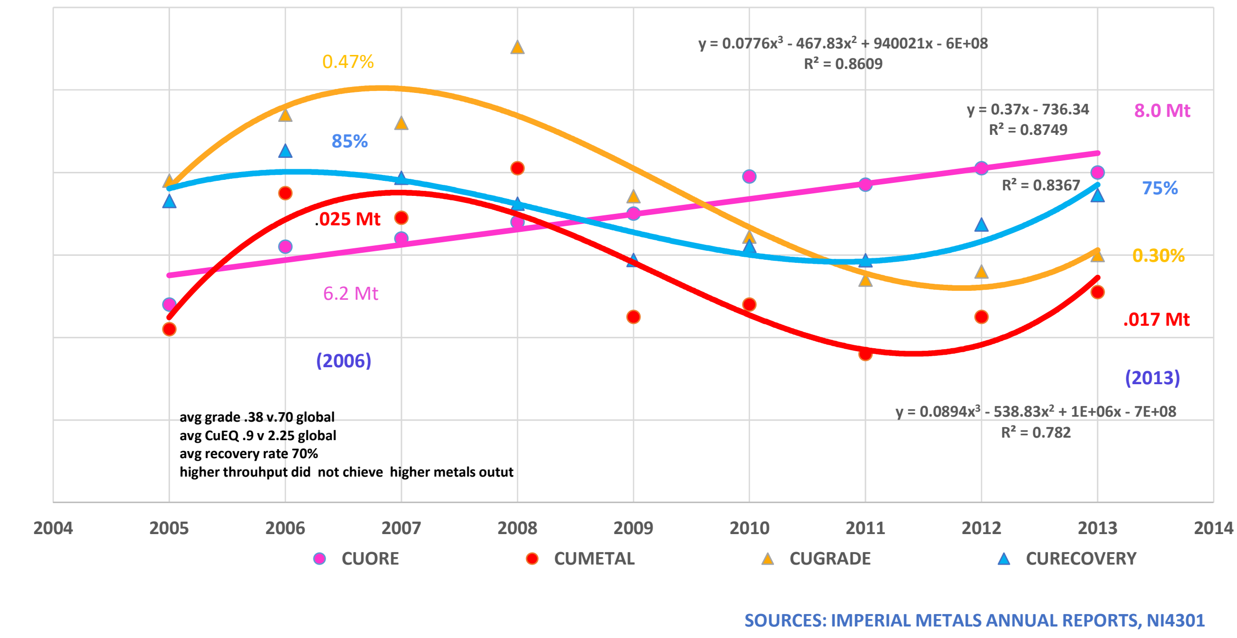
Mine level data is strongly persuasive that mines which produce "Very Serious" TSF failures are "poor performers" viz. average global econometrics. This in turn affirms a significant "public interest" in giving "economic feasibility" a specific and prominent place in mine and mine expansion approval and in life of mine, life of facility regulatory oversight.

In gold, as a respected analyst Mark Fellows explains, a 10% fall in global average ore grade gives rise to a $50/oz. rise in average global production costs (Fellows 2010). At the mine-level, a difference between a gold mine with 1.72g/t and 2.2 g/t translates to a likely cost difference of $100/oz. in total production costs. These are the actual differences at the Gold Ridge mine, Guadalcanal, in 2009. This mine never achieved profitability, not because of political unrest, but because of the low quality of the deposit compared to the quality of ores shaping world markets. Gold Ridge, with approximately 20 million cubic meters tailings storage capacity with a long history of many owners, frequent interruptions, and continually falling recovery rates (another emerging consequence of mining very low grade ores), under ownership of landowners with limited technical competence, has hovered on the brink of complete failure by overtopping for two years (Ausenco 2007).

4.3 Further Exploration of the Dimensionality of Relationship between Failures and Global Mining Economics

If the legal frameworks for mining mandated the maintenance of public information on the tailings facilities and their larger context of mine and miner on the mines they have approved (or are reviewing), it would be possible to directly compare mine-level with global economic profiles and develop proven "failure risk" markers that might help intercept the incubation of failure conditions early enough for correction before the failure occurs. This information doesn't exist in any permitting regime we have seen. We know from the mine-level narrative of catastrophic failures that poor vetting, shoestring economics and production schedules ahead of safety were very much the key backstory at Mt Polley, which never attained "economic feasibility". From the outset it was plagued by low grades and low recovery rates. A careful reading of all annual reports and of the NI 43-101 prepared by an in-house

FIG 6 MT POLLEY ECONOMICS PRE FAILURE



geologist indicates that the reopening in 2005 was based on sparse 4-year old data that was not independently verified or re-examined. Life of mine Average Cu Grade was 0.38 vs 0.70 global; higher throughput did not achieve higher metals output as recovery grades constantly were below expected. Imperial processed 29% more ore in 2013 as compared with 2006, its year of peak grade but produced 3.2% less metal. As is obvious in Figure 6 falling grades parallel metals output**.** Life of mine to failure, the Very Serious failure rate for Mt Polley is 0.011 per million tonnes of ore to the mill vs 0.0004 globally, that is 27 times higher than the global failure performance.

The amount of debt Samarco had amassed for the 2010 expansion put great weight on going forward. They did not stop to fix the Fundao dam, or to create more long term capacity onsite (Amira et al. 2010). Piecing this economic back story together for all failures into a data base has so far been impossible. But it is still possible to probe more deeply the dimensionality of the connection between failures and global economics over time at the aggregate level via canonical correlation analysis (CCA). CCA is a way of exploring whether two data sets, in our case the failures data set and the global economics data set, are independent. It can also help identify the dimensions of cross influences or common unidentified external influences (e.g. technical incompetence, brain drain, improper application of technology, geographic shifts in production advantage, excessive debt lost productivity).

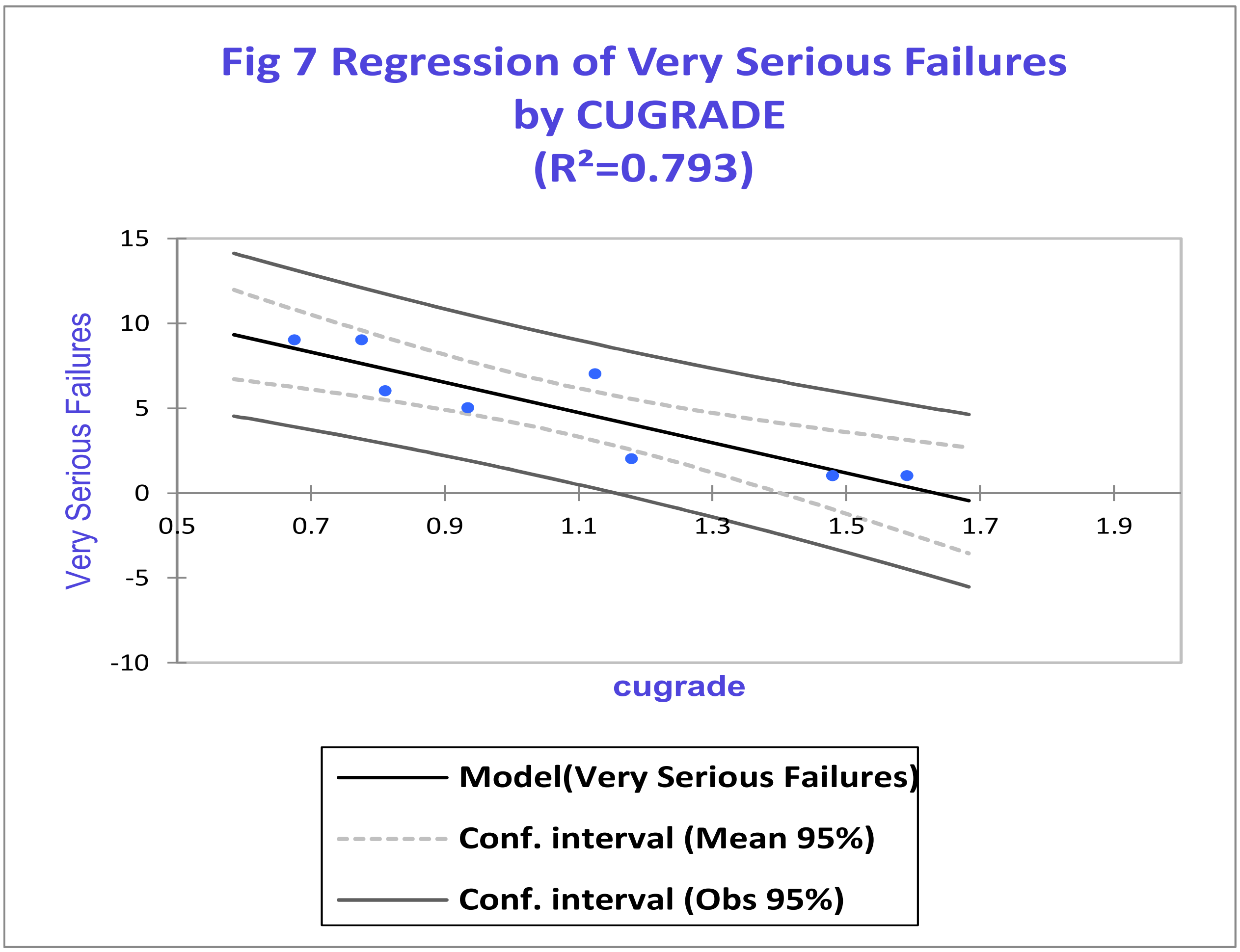
Prior research on failures 1940-2009 (Bowker & Chambers 2015) utilizing CCA strongly indicated that TSF failures and copper economics data sets are interdependent, and this is reaffirmed with data through 2015 (see Data base for technical documentation). More than 95% of the total variance is explained through the two canonical variables for both the pre-2010 and pre-2015 data sets. In both, extremely high eigenvalues (0.950 and 0.854), cumulatively explain 100% of the variation. These results strongly indicate the presence of a clear and powerful correlation between failures data and economics data that is linear in nature. The results also further suggest that there are no “missing variables” (no external latent variables commonly affecting both data sets). The Wilks Lambda variables for the entire CCA model for both pre 2010 (0.011) and post 2010 (0.007) data sets are extraordinarily low, supporting the assertion that the two data sets, failures and econometrics, are not independent.

TABLE 4 VERY SERIOUS FAILURES Correlations W Canonical Variables		
	1940-2009	1936-2015
CUPROD	-0.8285	-0.9136
CUGRADE	0.6064	0.8827
CUCOST	0.3982	0.5373

What is most notable though over only 6 years (2010-2015) is the change in the composition of the canonical variables again pointing to the strong influence of grade, as show in Table 4 below.

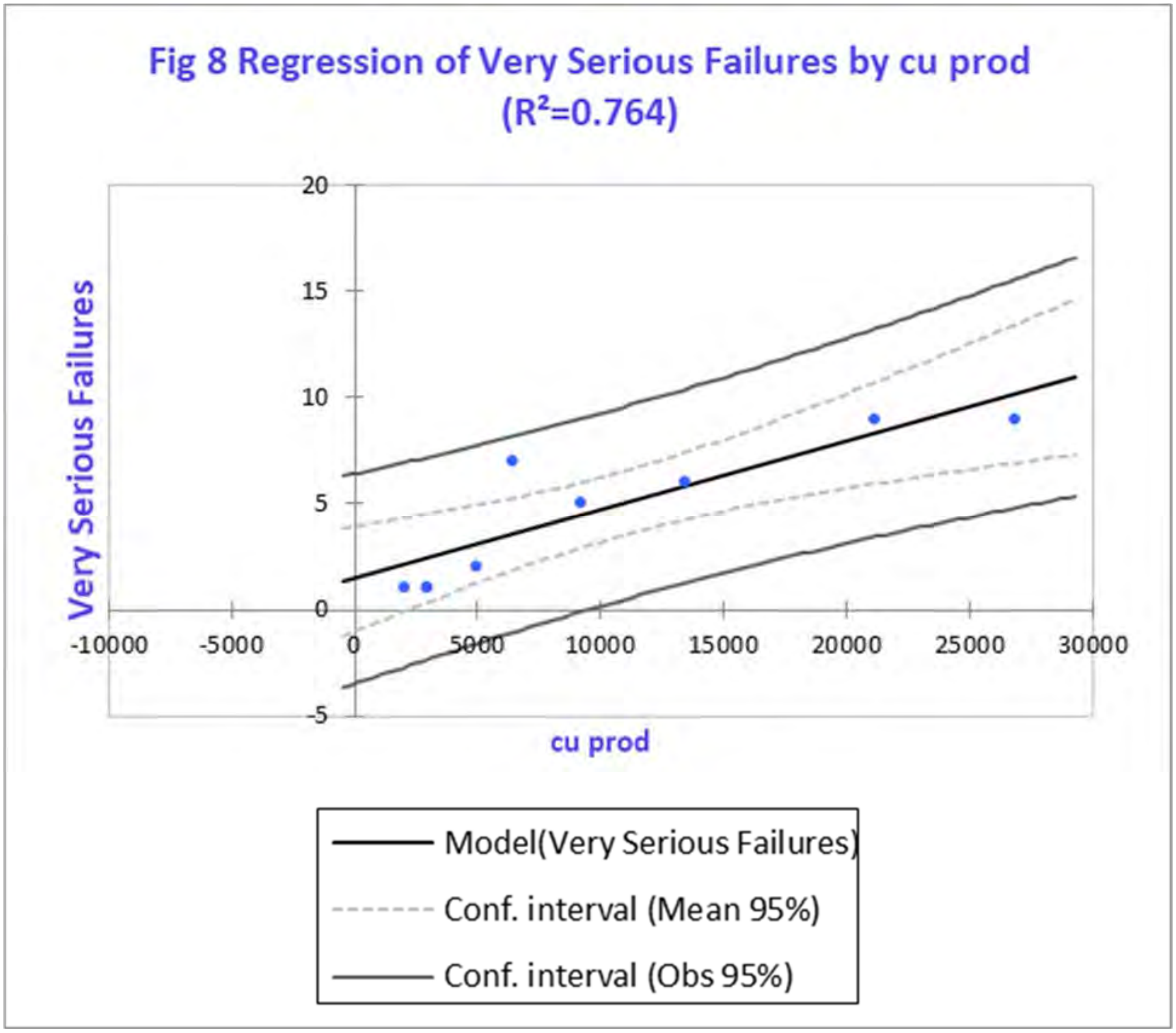
In the canonical variable most closely associated with Very Serious Failures, the correlations with the three mining economics variables is stronger for all 3 post 2010 v pre 2010. The most dramatic change is with grade from 0.6064 pre 2010, to 0.8827 post 2010.

The eigenvalues imply a very strong simple linear relationship between Very Serious Failures and both grade and ore production volume.



We undertook examination of these relationships through linear regression, again not to establish statistical significance but just to describe the relationships.

The regression of Very Serious Failures by grade explained 79% of the total variance as shown in Figure 7. Again, this confirms the very strong influence of global average mill grade on catastrophic failures.



The regression of Very Serious Failures by ore production volume (copper production - CUPROD), essentially tailings waste volume, explained 76% of total variance as shown in Figure 8.

5.0 CONCLUSIONS

Overlaying the supercycle autopsies of some of the world's top mining analysts onto what we previously documented in Bowker & Chambers (2015) explains the extent and nature of dysfunctions in global mine planning, development and operation that shaped what we previously had mapped and inferred from our data.

In their independent examination of the supercycle, there is a clear consensus among the world's top mining analysts that we have crossed the threshold into a new and as yet unclear era of mining. If it is understood at all, the industry its regulators and even its key investment analysts have not publicly recognized that present discovery and as milled grades have reached levels that are beyond presently known technology that had previously worked to create economic viability for low grade large scale mines. No regulatory agency known to us has recognized the need to reexamine the large scale low grade mining projects like KSM, Pebble, and Polymet that were originated in the frenzy of the supercycle on assumptions that were never proven in the first instance, and which are very clearly no longer true. No regulatory agency known to us has recognized that the supercycle was a time of pushing marginal mines and their existing infrastructure beyond design capacity and that, as at Mt. Polley and Samarco, those are practices in which failure incubates and matures.

Overlaying the supercycle autopsies of some of the world's top mining analysts onto what we previously documented in Bowker & Chambers 2015 explains the extent and nature of dysfunctions in global mine planning, development and operation that shaped what we previously had mapped and inferred from our data.

Neither the industry itself nor its regulators are taking realistic account of the implications of the fact that somewhere between 1/3 and 1/2 of all technically "operating" mines are no longer economically viable or never were viable. Such a high incidence of stranded assets does not indicate wellness for the industry as a whole. Regulators passively stand by while the wholesale dumping of these mines assuming that production will resume, that jobs will be retained, and that new revenue will finance identification and correction corrections of any potential flaws in infrastructure aggressively pushed into production levels beyond planned capacity. These are not assumptions supported by available data or expert economic analysis.

There is a clear consensus among the world's top mining analysts that we have crossed the threshold into a new and as yet unclear era of mining. If it is understood at all, the industry its regulators and even its key investment analysts have not publicly recognized that present discovery and as milled grades have reached levels that are beyond presently known technology that had previously worked to create economic viability for low grade large scale mines.

There isn't enough data to say what % of these no longer viable mines have TSF's large enough to cause catastrophic failure, but we have confidence in our prediction methods which accurately predicted the 9 very serious failures 2006-2015. We have confidence that the fall out of the supercycle dysfunctions will manifest in higher than previously expected Serious and Very Serious Failures. The data and our proven method of prediction tell us that the expected number of high severity failures is greater (13) than previously estimated for the decade 2010-2020, and that we can expect a record high of at least 15 in each high consequence category for 2016-2025.

The eminent eloquent and wise Dr. Dirk Van Zyl, who served on the Mt Polley expert panel, characterized Bowker & Chambers 2015 as "unnecessarily alarmist". That characterization is proven wrong by what we now can all more clearly see as a significantly elevated and not fully examined global portfolio risk of failure. History itself proves that characterization wrong. We had pieced together a patchwork quilt of costs and legal judgments on post 1990 Very Serious failures predicting $6 billion in 11 Very Serious failures 2010-2020. Samarco alone has damages that exceed that hobbled together estimate by at least 3 fold from a TSF with only a capacity of only 60 M m3. We now reasonably anticipate 13 not 11 Very Serious failures and an additional 13 Serious Failures based on actual ore production volumes and compilation and reconciliation of independent expert predictions post 2015.

Portfolio public liability risk is not going to simply self-correct to less elevated levels.

Nether MAC nor ICMM nor any mining jurisdiction we are aware of has undertaken any reforms that will be effective in lowering public liability portfolio risk.

In Risk Management we live by that old adage "an ounce of prevention is worth a pound of cure". Waiting for revenue that will never come to fix broken and no longer serviceable infrastructure is not in the public interest. It offers neither prevention nor hope of cure for whatever already formed catastrophic losses are maturing to final event.

Continuing to advance and tout mega scale low grade projects conceived in the supercycle and on the basis of its cowboy economics offers no reform, no future with better outcomes.

Regulators have clearly chosen protection and support for the mining industry over reducing public risk and public liability. That and past long standing issues of enormous gravity have brought a loud public backlash in anti-mining anger in the form of extreme and reactive legislation with outright complete prohibitions on all metallic mining , bans on open pit mining, bans of varying degrees on all upstream construction and in the case of Maine, a state with only two mines ever, both failures with a high unresolved unfunded public consequence, a tantamount complete ban in the form of a requirement to prefund in cash an independently assessed worst case scenario.

Regulators have clearly chosen protection and support for the mining industry over reducing public risk and public liability. That and past issues of long standing gravity have brought a loud public back lash in anti-mining anger and disgust in the form of extreme and reactive legislation. If regulators and the industry do not address themselves more actively to pubic risk and public liability than they have done to date 3 years after Mt Polly and two years after Samarco, it is reasonable to expect that elevated public outrage will spawn more of these public opinion driven reactionary extreme anti mining proposals.
While all that unfolds as it will, our data say the public liability risk continues to elevate and the consequence of failure continues to grow.

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