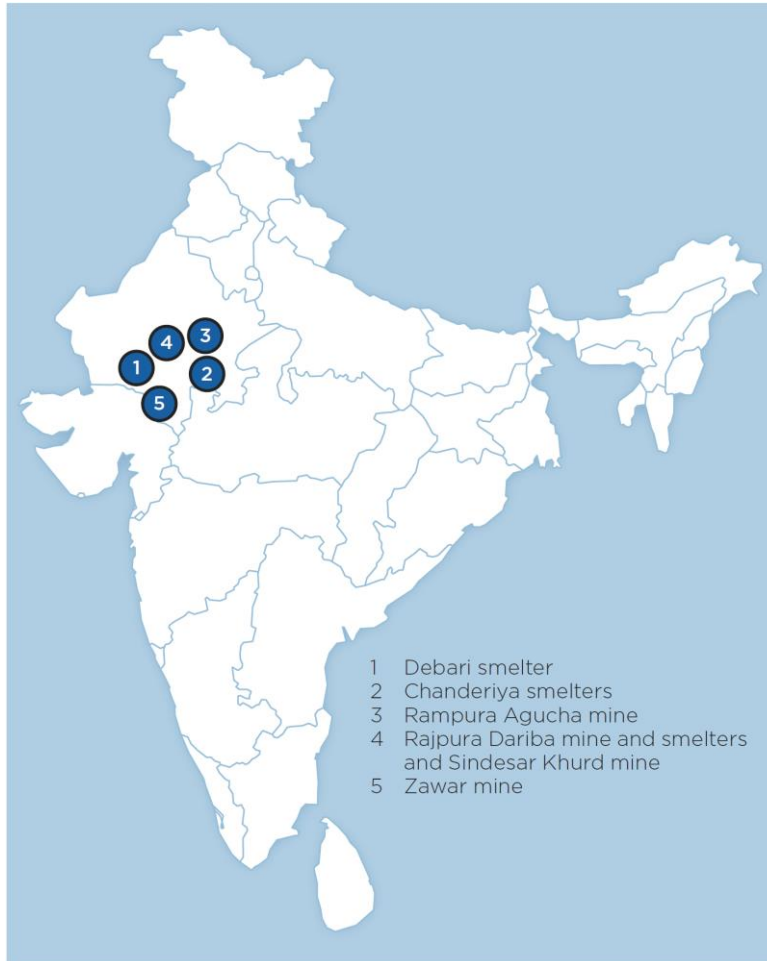


**MODULE 4- ZINC MINING IN INDIA**

Zinc mining in India is conducted exclusively by Hindustan Zinc Limited (HZL) which is a subsidiary of Vedanta Limited. Five zinc mines are currently in operation. The reserve and resource base is excellent as illustrated in Table 1. The deposits in India are classic metamorphosed SEDEX type deposits.



**Table 1 Reserves and Resources at HZL as of March 31, 2016**

	Proven and Probable Reserves				Measured and Indicated Resources				Inf. T
	MT	Zinc %	Lead %	Ag g/t	MT	Zinc %	Lead %	Ag g/t	MT
Rampura Agucha OP	8.8	13	1.9	52					
Rampura Agucha UG	42.3	14.1	1.8	60	14.8	15.2	2	63	37.9
Rajpura Dariba	9.3	6.3	1.6	61	22.8	6.9	2.3	66	26.6
Sindesar Khurd	33.2	4.7	3.2	187	23.6	4.7	2.8	138	52.7
Zawar	9.5	3.4	1.7	32	26.2	4.7	1.8	67	56.1
Kayad	3.9	13.4	1.8	43	1.7	12.3	1.8	41	0.4
	107				89.1				173.7

MT= million tonnes ore Inf. T = Inferred tonnes

When I first started to look in depth at HZL my concern was the fact that the Rampura Agucha Mine (RAM) open pit was quickly running out of reserves. The above table illustrates only 8.8 million tonnes of reserves left and this has previously been mined at up to 6 million tonnes a year.

The open pit has been, until recently, the world's largest annual zinc producer. My concern was obviously HZL's also since they are in the process of conducting a mad scramble to expand other operations and develop the underground portion of RAM to make up this pending shortfall. This is described in detail below. If HZL fails to execute on their expansion plans there could be a sharp drop in zinc output from India.

In previous modules I have had the luxury of reviewing numerous NI 43-101 reports and Annual Information Forms to form my opinions. I guess we can thank Bre-X for leading to this high degree of transparency in North American markets. Unfortunately, this transparency has not extended overseas where numerous entities still consider information to be power and not sharing it with others to be a competitive advantage. I have to fall back on my background to come up with my own conclusions as to likely outcomes going forward in these situations including this one. So if what I state in this report has some inaccuracies you can only thank HZL and Vedanta for this.

### **Rampura Agucha Mine**

Mineralization is contained in a banded gneissic complex. The host for the ore is a graphite-mica-sillimanite schist. My experience with this type of rock (at the Geco base metal mine in Canada) is that it is weak and often unstable which leads to difficulties when blasthole stoping in particular.

The strike length of the steeply dipping massive mineralization is 1,400 m and the depth is roughly 800 m. Average width is 58 m but reaches 100 m. Open pit mining to a depth of 421 m is under way with underground mining commencing recently to extract mineralization below pit bottom using blasthole stoping methods.

Production in the open pit commenced in 1989 and after multiple mill expansions the mill can now treat in excess of 6 MT of ore annually. Limited production in the underground portion commenced in 2013.

### **RAM Open Pit**

Table 2 lists recent production performance from this incredible cash cow. As discussed later, HZL realized in 2013 that the RAM underground development program was falling well behind schedule so made the correct decision to deepen the open pit mine from 380 m to 421 m depth in order to extract more ore from it. What this has meant however is that a great deal of waste stripping is necessary to push back the pit walls to access this ore at or near the bottom of the pit. Ore mining is not continuous.

This has led to a temporary large recent drop in production (Q1 and Q2 FY 2017) from the site which has flowed through to their smelters. The competition for zinc concentrate is so fierce currently treatment charges have collapsed. HZL was not able to source concentrate to make up for the lost open pit production and were in fact forced to purchase refined zinc from other suppliers in order to satisfy their customers.

**Table 2 Recent Rampura Agucha Milling Results by Financial Year**

	<b>FY 2010</b>	<b>FY 2011</b>	<b>FY 2012</b>	<b>FY 2013</b>	<b>FY 2014</b>	<b>FY 2015</b>	<b>FY 2016*</b>
Tonnes milled	5,152,470	5,856,380	5,982,360	6,168,000	5,804,000	5,394,000	5,465,000
Zn grade milled	12.92%	13.09%	11.98%	12.30%	12.40%	13.00%	11.60%
<b>Zn in concentrate</b>	<b>612,940</b>	<b>677,430</b>	<b>649,580</b>	<b>677,300</b>	<b>652,700</b>	<b>640,800</b>	<b>588,100</b>
Implied recovery	92.1%	88.4%	90.6%	89.3%	90.7%	91.4%	93.0%

**Includes ore from:**

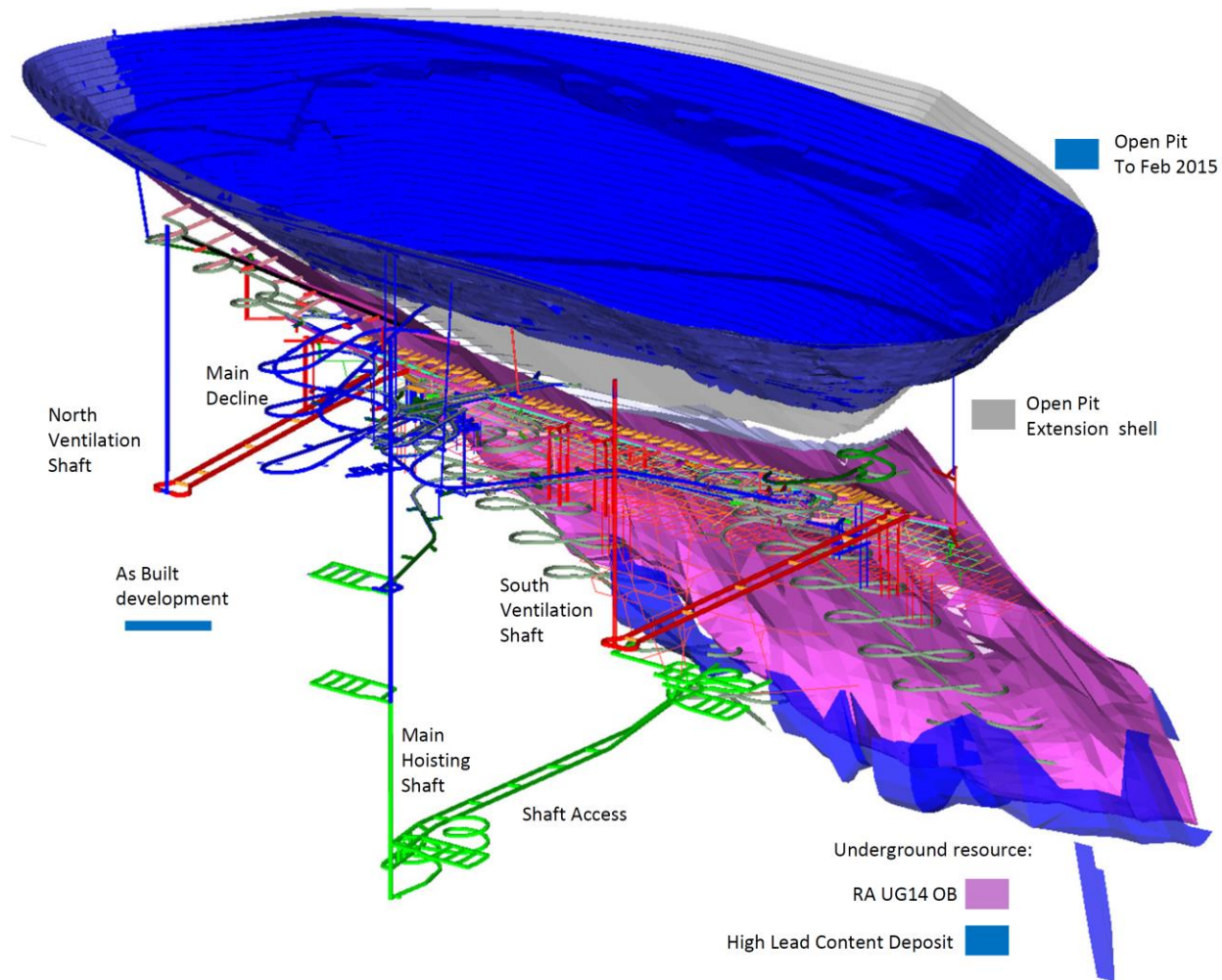
RAM UG	320,000	????	????
Kayad		370,000	760,000

Note: FY 2016 ended March 31, 2016. \*Tonnes mined. Kayad mined grade in FY 2016 was 8.9% Zn and RAM grade was 12.0% Zn. Kayad ore is milled at RAM so has been added to RAM milling results. ????= likely too embarrassing to report due to missed guidance.

HZL expects to mine the remaining 8.8 million tonnes of open pit ore in two tranches. Based upon conference call transcripts I have estimated that the first significant tranche of ore will commence in approximately November, 2016 and continue for roughly a year. After further waste stripping I assume the second tranche of ore will commence in November, 2018 and also continue for about a year. I have assumed each tranche will equal 50% of the current reported reserves.

Three sources of ore feed the mill: the RAM open pit, RAM underground and the neighboring Kayad mine. At times the combined mining of all three sources will exceed the milling capacity of 6 MT per annum or 1.5 million tonnes per quarter. Later in Table 3, I present the combined milling schedule forecast to 2022 for all three sources. I have assumed the temporary stockpiling of open pit ore when the mill is at capacity.

The open pit mine and related underground development is illustrated in Figure 1 below. In grey is the necessary push back to access the deeper pit bottom.



**Figure 1 A Schematic Showing Actual and Planned Open Pit and Underground Development at Rampura Agucha**

Underground development completed as of February 2015 is highlighted in blue. Unfortunately, HZL has dropped this figure from more recent presentations and I suspect this may be potentially due to not wanting to raise alarm bells at the lack of progress underground at depth since then.



The pit walls do not look terribly attractive to me and are likely indicative of weak rock units. Reportedly, a considerable amount of cable bolting is conducted for these walls which is unusual for open pits. I have assumed all goes well with planned mining but as the Bingham Canyon pit in Utah experienced recently, you never know.

## RAM Underground

HZL states that the underground mine is being developed for an eventual underground production rate of 3.75 MT per annum. HZL states delays have been encountered due to “difficult geotech conditions”.

Slow progress in the sinking of the production shaft also appears to be related to the interception of a water bearing fault between 600-630 m depth that required extensive grouting. Whether there have been further groundwater interceptions that could hinder advance and whether the water is readily recharged is uncertain but the water was reported to be hot which could also betray a high geothermal gradient (in other words, it could be stinking hot underground, like the rest of India I guess).

Production figures to date underground have not been terribly encouraging. The FY2014 Annual Report states that 320,000 tonnes of ore was mined underground at RAM that year (ending March 31, 2014) via the ramps.

No underground production figures were provided for FY2015 or FY 2016 in the Annual Reports. However, in their recent 20-F filing with the SEC Vedanta states that 62.6 MT of waste was mined from the pit at a 14:1 waste:ore strip ratio and that a total of 4.7 MT was mined at RAM for the year. This strip ratio implies open pit production was roughly 4.5 MT (62.6/14) leaving only 0.2 MT for the underground portion. They state “the underground project (is) picking up pace after a slower than planned ramp up due to difficult geotech conditions”.

The recent Q1 FY2017 release states that the mine “crossed one million MT per annum production rate during the quarter”. In other words they are producing at about a 90,000 tonnes per month rate currently. This is a far cry from 3.75 MT per annum, or over 300,000 tonnes per month.

This ore is being hauled up the two declines to surface. Full production is not possible until the shaft, crushing and loading pocket system is commissioned underground. This is the lime green development shown in Figure 1. They are currently on the level and tunneling towards the crusher area from what I can gather. Having been through this process before myself at three different base metal mines, I would estimate that they are two years away from commissioning the crushing/conveying and skipping system. Let’s call it October, 2018 (Q3 FY2019) which could be charitable. The shaft also needs to be sunk to final planned depth. In the meantime, I cannot see them hauling more than 1.5 MT per annum to surface via the existing declines prior to then since the haul to surface will be over 500 vertical metres.

So based on all of the above, Table 3, presented later, is my interpretation of their production schedule for the underground mine to 2022. This assumes they get on top of and stay on top of all the geotechnical issues they have encountered. For instance, if the ground really is weak, will the ore pass system from mining horizons to the crusher be stable?



## Kayad

The geology of this deposit has some similarities with RAM. The geology is characterized by gneisses and migmatites with quartzite, calcsilicates and quartz-mica schists. Mining is planned to roughly 400 m depth. It was discovered in the late 90's and the decision to develop it now was likely in recognition of the RAM ore supply issues and available milling capacity currently at RAM.

Ore from Kayad is hauled to RAM for milling. This mine has ramped up production to 1 MT per annum using blasthole stoping.

The reserve tonnes and grade reported in the FY2015 Annual Report were 7.3 MT @ 9.6% Zn but have been lowered to 3.9 MT @ 13.4% Zn in the FY2016 Annual Report without explanation by HZL or Vedanta (that I could find anyways). This could be due to the desire to high grade this resource, or planning to mine only one of three lenses or perhaps due to complaints by local villagers who sit literally on top of the deposit and whose beds likely shake with every midnight blast. Your guess is as good as mine.

Table 3 includes my production guesstimate for Kayad going forward. I have increased the mining grade from recent performance to near the new reported reserve grade. I have also added a healthy portion of resources into the schedule. To be honest, I had never heard of this mine prior to initiating this look into HZL and Vedanta so I am just regurgitating what I have discovered. With a quick ramp up in production though, it looks like they know what they are doing.





### Rampura Agucha Milling

Now that mining schedules have been generated for all the supply sources, total output at the RA mill can be estimated. The reason this is an important exercise is to see if there will be a substantial drop in output after the first tranche of mining in the pit is complete and to determine when the impact of total pit exhaustion will occur. Table 3 presents my findings. Note that this is based on calendar years. The current financial year extends to March 31, 2017. If all goes according to plan a full quarter of production from the open pit will occur during Q4 FY 2017 (Jan. 1 to March 31, 2017) to then better match HZL public statements for annual zinc production. However, calendar year 2016 production will be hampered by this lack of feed until late in the calendar year. HZL readily concedes this.

**Table 3 Estimated Rampura Agucha Mill Zinc in Concentrate Output, 2016-2022**

Calendar Year		2016	2017	2018	2019	2020	2021	2022	Total
<b>Rampura Agucha OP</b>	'000 t	1,150	3,150	500	2,800	1,200			8,800
Grade	% Zn	13%	13%	13%	13%	13%			
Contained Zn	'000 t	150	410	65	364	156			
Recovered Zn	'000 t	136	373	59	331	142			
<b>Rampura Agucha UG</b>	'000 t	1,000	1,300	1,800	2,300	3,200	3,500	3,500	16,600
Grade	% Zn	14.10%	14.10%	14.10%	14.10%	14.10%	14.10%	14.10%	
Contained Zn	'000 t	141	183	254	324	451	494	494	
Recovered Zn	'000 t	128	167	231	295	411	449	449	
<b>Kayad UG</b>	'000 t	1,000	1,000	1,000	1,000	1,000	500		5,500
Grade	% Zn	11%	13%	13%	13%	11%	9%		
Contained Zn	'000 t	110	130	130	130	110	45		
Recovered Zn	'000 t	100	118	118	118	100	41		
Milled Tonnage	'000 t	3,150	5,450	3,300	6,100	5,400	4,000	3,500	30,900
<b>Zinc in Concentrate</b>	<b>'000 t</b>	<b>364</b>	<b>658</b>	<b>408</b>	<b>745</b>	<b>653</b>	<b>490</b>	<b>449</b>	

Table 3 adequately demonstrates the erratic nature of production at RAM based upon varying production levels from the open pit. By 2020, the mill will be solely reliant upon underground ore so further delays at RAM underground will have major ramifications on output. Nevertheless, site zinc production levels will fall to roughly two thirds of the output achieved in recent years.

**Sindesar Khurd Mine (SKM)**

Ground conditions at this underground mine are reported to be very good. This and the shallow nature of the ore has likely contributed to its rapid ramp up in production in recent years. Table 4 illustrates this ramp up. A production rate of 3.75 MT per annum is planned and there has been some discussion on possibly increasing this.

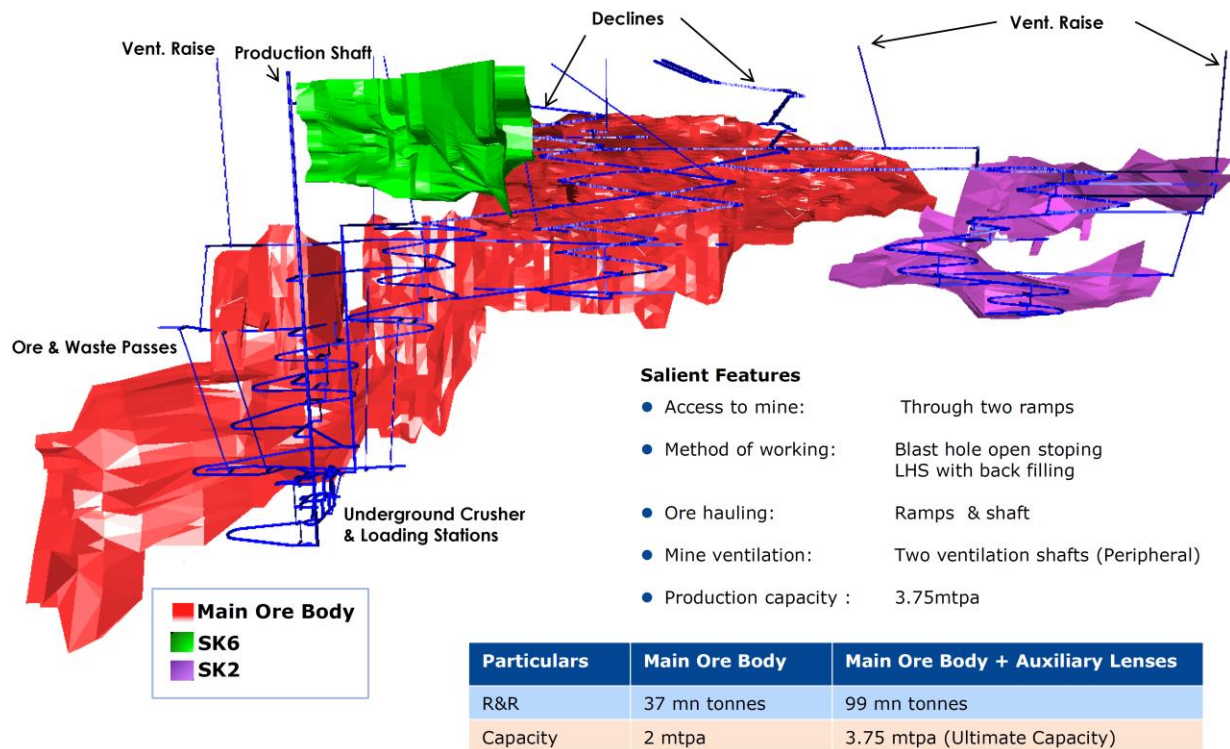
**Table 4 Recent Sindesar Khurd Mining Results by Financial Year**

	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	FY 2016*
Tonnes milled	442,870	607,430	1,370,340	1,585,000	1,723,000	1,943,000	2,970,000
Zn grade milled	5.44%	5.38%	4.44%	4.40%	3.50%	3.60%	3.90%
<b>Zn in concentrate</b>	<b>19,750</b>	<b>26,690</b>	<b>51,150</b>	<b>52,600</b>	<b>53,600</b>	<b>65,100</b>	<b>91,000</b>
Implied recovery	82.0%	81.7%	84.1%	75.4%	88.9%	93.1%	78.6%

\*I am not sure why the recoveries are bouncing around so much but I suspect it is related to stockpiling of ore on surface.

What I find pretty remarkable about this operation is the fact that they are currently hauling over 3 MT of ore to surface with only two declines. This is not an easy task since the declines are the only means into the mine and are usually very congested. I am at a loss as to how they are doing it. The production shaft will reportedly not be commissioned until 2018.

What is important to note though is this mine will likely be best known as a silver mine. Zinc grade is only roughly one third that of RAM so pushing more tonnage does not necessarily counter pending zinc shortfalls at RAM.



In Table 5, I have assumed they will be able to feed the expanded mill capacity throughout the study period and that the milled grade will increase steadily when they have more source flexibility.

**Table 5 Forecast Sindesar Khurd Zinc Production by Calendar Year**

Calendar Year		2016	2017	2018	2019	2020	2021	2022	Total
<b>Sindesar Khurd</b>	'000 t	3,300	3,300	3,500	3,700	3,700	3,700	3,700	24,900
Grade	% Zn	4.2%	4.5%	4.8%	5.1%	5.1%	5.1%	5.1%	
Contained Zn	'000 t	139	149	168	189	189	189	189	1,210
Recovered Zn	'000 t	115	123	139	157	157	157	157	1,004

One thing I noticed during this review is that the mines annual zinc grade is always consistently below the respective reserve grade. Either HZL are not acknowledging actual dilution levels or they are including lower grade resources into their annual mine plans. For mines with large reserve bases, annual grades should be higher than reserve grade since they can afford to be choosy.

### Rajpura Dariba Mine

If I thought I knew little about Kayad, I know even less about this operation so I pretty much have to accept what the company states at face value with caveats. Mining commenced in 1984. For a reserve and resource base of over 60 MT they sure are hitting this one in a pretty pedestrian fashion as illustrated in Table 6. HZL tells us that they will increase production from 900,000 T per annum to 1,200,000 T per annum shortly. The problem is, the mine has not gotten appreciably above 600,000 T per annum yet. I suspect we are being told what the mill can process, not what the mine can feed it which is a different matter.

**Table 6 Recent Rajpura Dariba Zinc Production by Financial Year**

	<b>FY 2010</b>	<b>FY 2011</b>	<b>FY 2012</b>	<b>FY 2013</b>	<b>FY 2014</b>	<b>FY 2015</b>	<b>FY 2016</b>
Tonnes milled	499,230	497,090	614,650	561,000	610,000	573,000	669,000
Zn grade milled	5.34%	5.65%	5.43%	5.40%	5.40%	5.30%	5.10%
<b>Zn in concentrate</b>	<b>21,960</b>	<b>23,190</b>	<b>27,790</b>	<b>25,200</b>	<b>26,500</b>	<b>25,400</b>	<b>31,800</b>
Implied recovery	82.4%	82.6%	83.3%	83.2%	80.4%	83.6%	93.2%

What little I do know about this mine is that it has a strike length of 1,600 m and varies in width from 6 m to 30m. Mineralization has been traced at least to 800 m depth. The dip is 60 to 70 degrees. Access is via two shafts and blasthole stoping is used. Ore haulage is by locomotives with 5 ton Granby cars feeding 6 ton balanced skips to surface. This could be why expanding the mine is difficult; lack of hoisting capacity hamstrung with 1930's rail haulage technology. Switching to trackless mining is difficult if not virtually impossible since the tunnels are too small for sizable mobile equipment and the mine likely lacks the ventilation capacity for diesel equipment also. So only small incremental increases in production are likely unless a major capital expansion project is announced. I have reflected only incremental increases in Table 7 despite what HZL says.

**Table 7 Forecast Rajpura Dariba Zinc Production by Calendar Year**

<b>Calendar Year</b>		<b>2016</b>	<b>2017</b>	<b>2018</b>	<b>2019</b>	<b>2020</b>	<b>2021</b>	<b>2022</b>	<b>Total</b>
<b>Rajpura Dariba</b>	'000 t	700	800	900	1,000	1,000	1,000	1,000	6,400
Grade	% Zn	5.3%	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%	
Contained Zn	'000 t	37	44	50	55	55	55	55	351
Recovered Zn	'000 t	31	37	41	46	46	46	46	291

## Zawar

Many of the comments I made for the Rajpura Dariba mine appear to apply here also. There are actually four separate mines that comprise Zawar: Mochia, Balaria, Zawarmala and Baroi. Three of these mines were closed recently for a few years due to regulatory reasons. Table 8 illustrates recent production. I jested in a previous Module that one mine started mining shortly after the crucifixion of Christ. Well guess what? They did here, before actually.

**Table 8 Recent Zawar Zinc Production by Financial Year**

	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	FY 2016
Tonnes milled	1,013,580	459,300	267,040	277,000	1,004,000	1,077,000	1,350,000
Zn grade milled	3.05%	3.66%	3.78%	3.80%	2.80%	2.80%	2.80%
<b>Zn in concentrate</b>	<b>28,120</b>	<b>24,810</b>	<b>10,050</b>	<b>9,600</b>	<b>25,700</b>	<b>27,400</b>	<b>33,300</b>
Implied recovery	91.0%	147.6%	99.6%	91.2%	91.4%	90.9%	88.1%
		wtf?	wtf?				

If you have nothing better to do with your lives for the next 20 minutes you can get a sense of these operations [here](#) and [here](#) . Dig the background music and the trip down the shaft. Pray everyone on the cage was not eating garlic beforehand. This is the way mines were set up prior to the introduction of mobile equipment in the 1980's. Visit the jaw crusher 1,000 m below surface. Jaw crushers are still quite common today. They are used to reduce the size of ore to bread basket size so it can be transported on conveyors to the shaft and hoisted to surface. This one looks very small though.

As illustrated in Table 1 there is a good reserve and resource base here. The problem is, it is low grade. So these mines will definitely be on the bottom rung with respect to capital allocation.

Table 9 is my estimate of production going forward.

**Table 9 Forecast Zawar Zinc Production by Calendar Year**

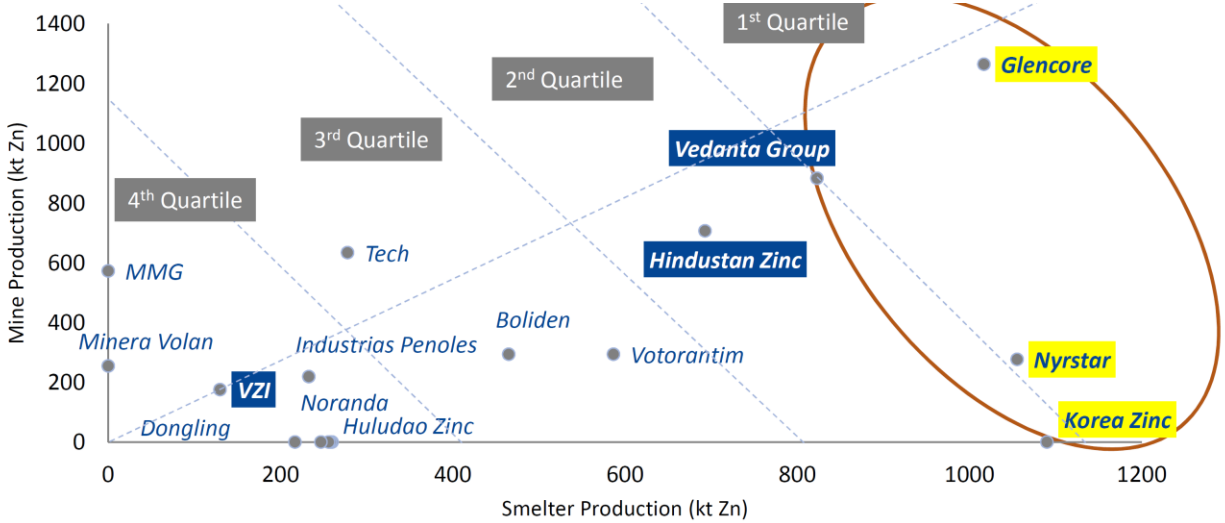
Calendar Year		2016	2017	2018	2019	2020	2021	2022	Total
<b>Zawar</b>	'000 t	1,300	1,300	1,300	1,300	1,300	1,300	1,300	9,100
Grade	% Zn	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	
Contained Zn	'000 t	39	39	39	39	39	39	39	273
Recovered Zn	'000 t	36	36	36	36	36	36	36	251

**HZL Smelting Capacity**

HZL currently operates three smelters in India and their capacities are listed in Table 10. Vedanta/HZL are only one of two large zinc miners that I am aware of (Glencore being the other) that have a close match between mining and smelting capacity as illustrated below. This means they have some pricing power and are not held to ransom by either custom smelters or miners, not yet anyways.

**Table 10 Recent Zinc Smelter Production and Smelter Capacity**

Smelter	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	FY 2016	Capacity
Chanderiya	436,909	424,418	464,021	443,074	476,950	464,724	488,470	525,000
Debari	87,347	84,839	68,046	68,445	74,501	69,385	66,764	88,000
Vizag	54,184	38,663	28,445	0	0	0	0	0
Dariba	0	164,551	198,204	165,403	197,715	199,694	203,704	210,000
	578,440	712,471	758,716	676,922	749,166	733,803	758,938	823,000



**HZL Actual and Forecast Zinc Production Summary**

So having laboured through my look at all the assets in India, I can total up all the recent and forecast production results. This is presented in Table 11. These results were a bit of a shocker to me. HZL has done their homework well. My hats off to them.

**Table 11 Recent and Forecast Zinc Production for HZL**

Mining	Financial Year*							Calendar Year							
	FY2010	FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	2016	2017	2018	2019	2020	2021	2022	
RA Mill*	612.9	677.4	649.6	677.3	652.7	640.8	588.1		364.0	658.0	408.0	745.0	653.0	490.0	449.0
Sindesar Khurd	19.8	26.7	51.1	52.6	53.6	65.1	91.0		115.0	123.0	139.0	157.0	157.0	157.0	157.0
Rajpura Dariba	22.0	23.2	27.8	25.2	26.5	25.4	31.8		31.0	37.0	41.0	46.0	46.0	46.0	46.0
Zawar	28.1	24.8	10.0	9.6	25.7	27.4	33.3		36.0	36.0	36.0	36.0	36.0	36.0	36.0
	682.8	752.1	738.5	764.7	758.5	758.7	744.2		546.0	854.0	624.0	984.0	892.0	729.0	688.0
Smelting	Actual Smelter output							Smelting Capacity only- not forecast output							
	2010	2011	2012	2013	2014	2015	2016		2016	2017	2018	2019	2020	2021	2022
Chanderiya	436.9	424.4	464.0	443.1	477.0	464.7	488.5		525.0	525.0	525.0	525.0	525.0	525.0	525.0
Debari	87.3	84.4	68.0	68.4	74.5	69.4	66.7		88.0	88.0	88.0	88.0	88.0	88.0	88.0
Vizag	54.2	38.7	28.4	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dariba	0.0	164.5	198.2	165.4	197.7	199.7	203.7		210.0	210.0	210.0	210.0	210.0	210.0	210.0
	578.4	712.0	758.6	676.9	749.2	733.8	758.9		823.0	823.0	823.0	823.0	823.0	823.0	823.0

\*Includes ore from RA open pit, RA underground and the Kayad mine. The financial year ends March 31, Indian humor I gather. Therefore FY2016 is April 1, 2015 to March 31, 2016. My forecasts are in calendar years along with all other companies assessed.

What the table reveals is the current 2016 shortage in concentrate necessary to feed their smelters which they readily acknowledge. This problem however is alleviated in 2017 when they will produce a modest concentrate surplus which can be used to feed their smelters in 2018 when mining is also somewhat short of requirements. Following this however, there will be no noticeable shortage in concentrate necessary to maintain the smelters at recent output levels through to 2022.

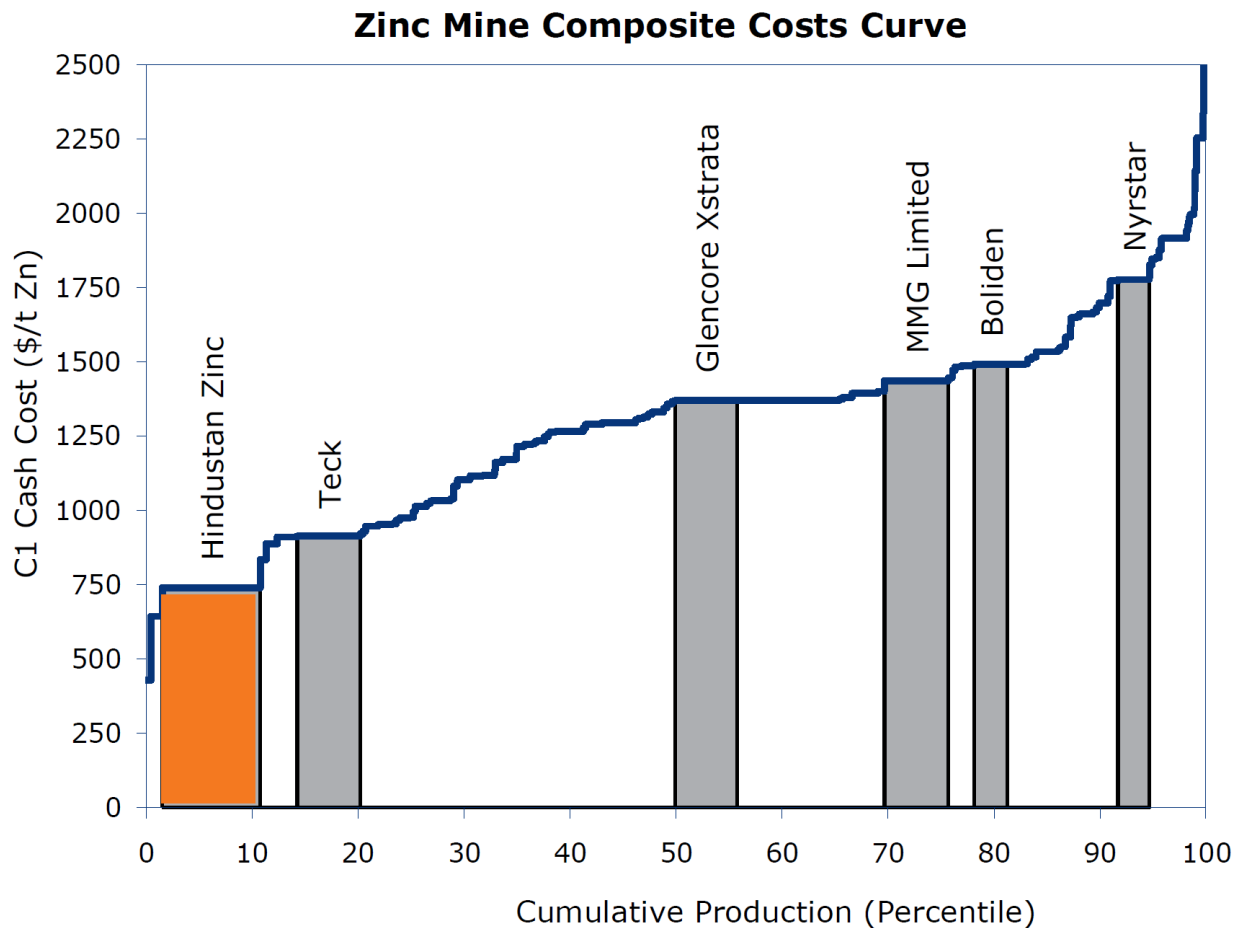
**Summary and Conclusions**

Well, I got to be honest with you. When I first started looking at HZL I thought to myself, “boy is the zinc market about to get a kick in the nuts they don’t appreciate yet” with the exhaustion of the RAM open pit. This is why I wanted to look at HZL early on in my assessment of the zinc miners.

After taking a good look though, HZL has definitely earned my respect. The lynchpin to this entire assessment however is underground mining at Rampura Agucha getting over its current ramp up challenges and being able to get to the new pit bottom without hiccups. So this is the key item to watch and based on generally poor disclosure, the key item you may have trouble finding accurate information for.

HZL will work hard to maintain production but they are no longer a threat to increase it.

I will definitely be taking a closer look however at Vedanta which trades on the NYSE (ADR’s). HZL trades on the Bombay Stock Exchange with the float at only 35%. The long life of these assets is a major attraction. They are also firmly planted in the first quartile of costs currently. This may vary once the RAM pit is exhausted. But my kudos to them anyways. They can survive any price downturn.





**DISCLOSURE**

The author had received no compensation for the generation of this report. The author may, from time to time have a long or short position in securities mentioned and may make purchases and/or sales of those securities in the open market.

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