TATA STEEL

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IMPLEMENTATION OF QAQC PRACTICES IN EXPLORATION : A CASE STUDY OF SUKINDA CHROMITE DEPOSIT

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AGENDA

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2.2	Exploration: Strategy, Challenges and Mitigation Measures
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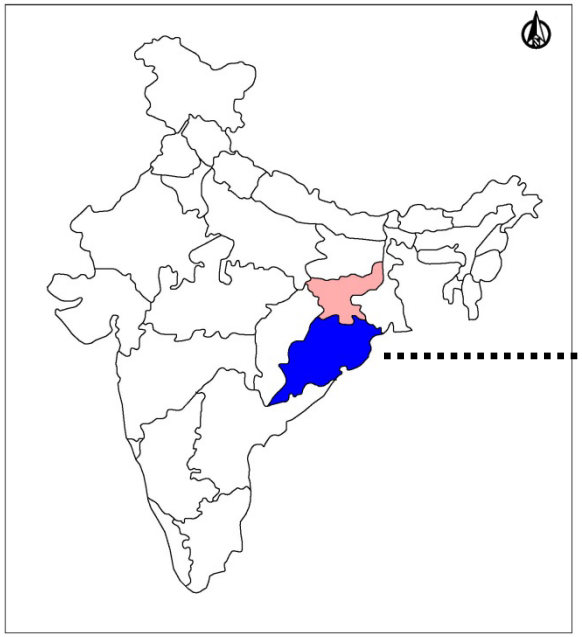
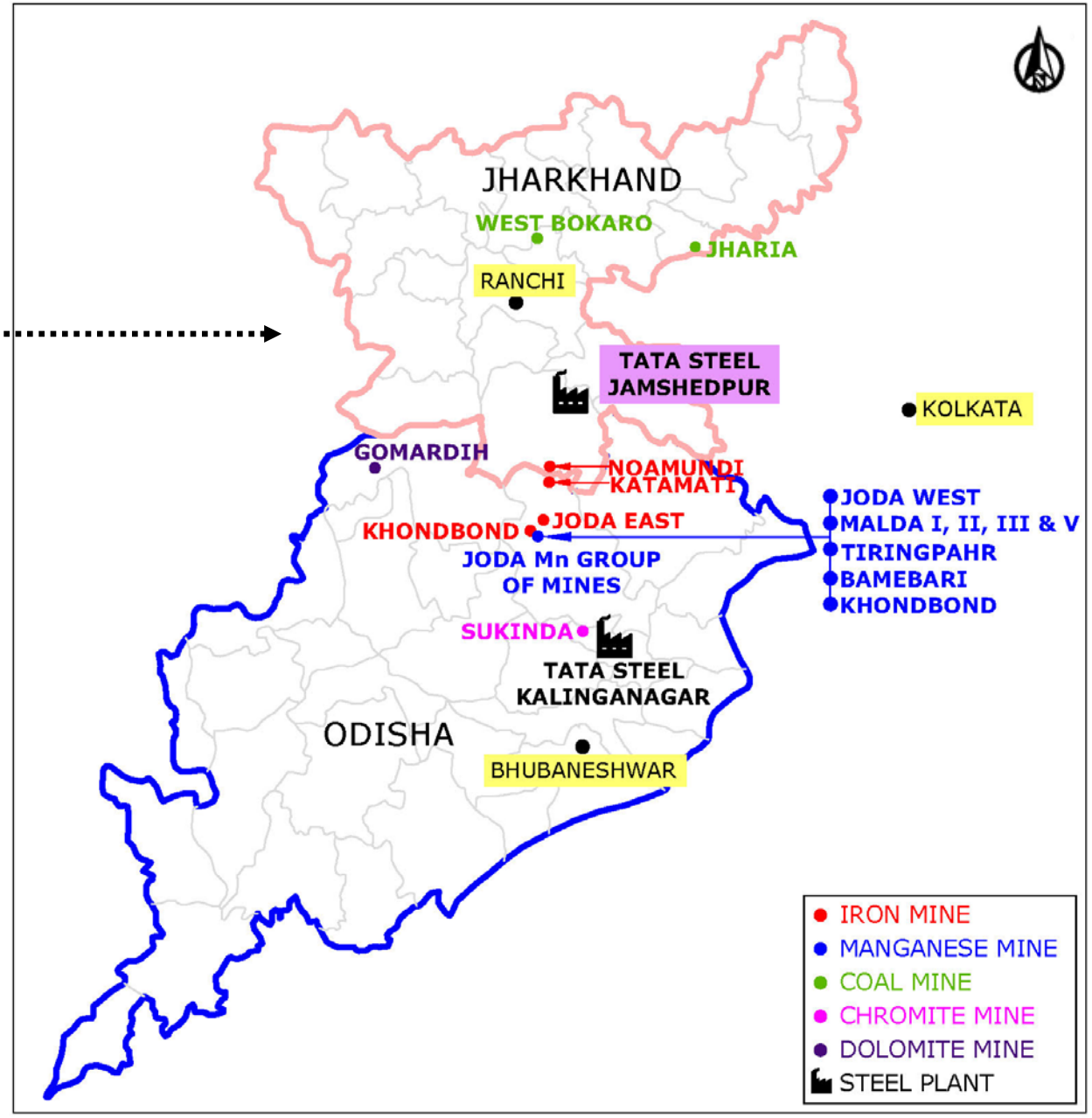
1. TATA STEEL LTD – SNAPSHOT: OPERATING MINES

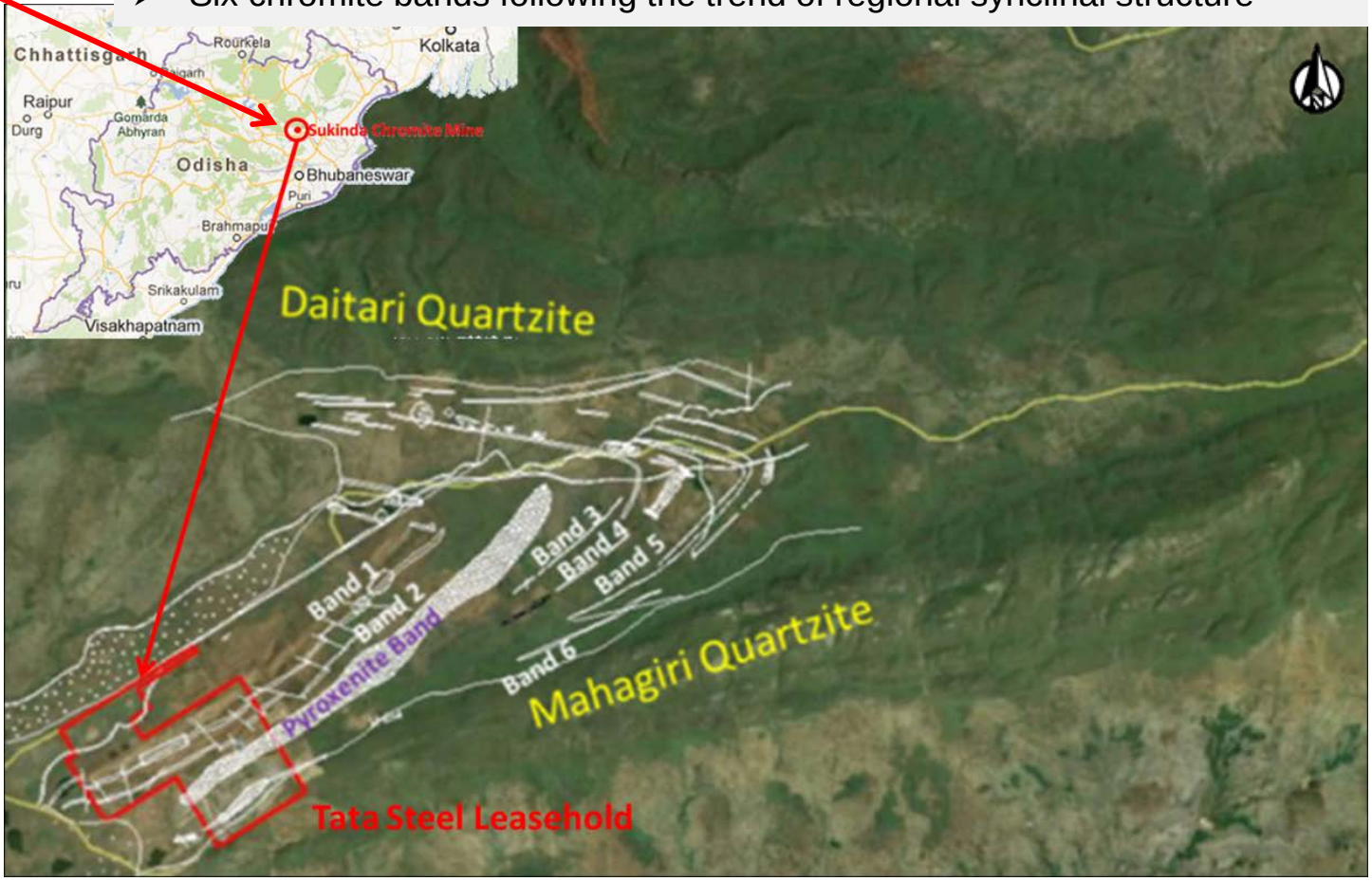




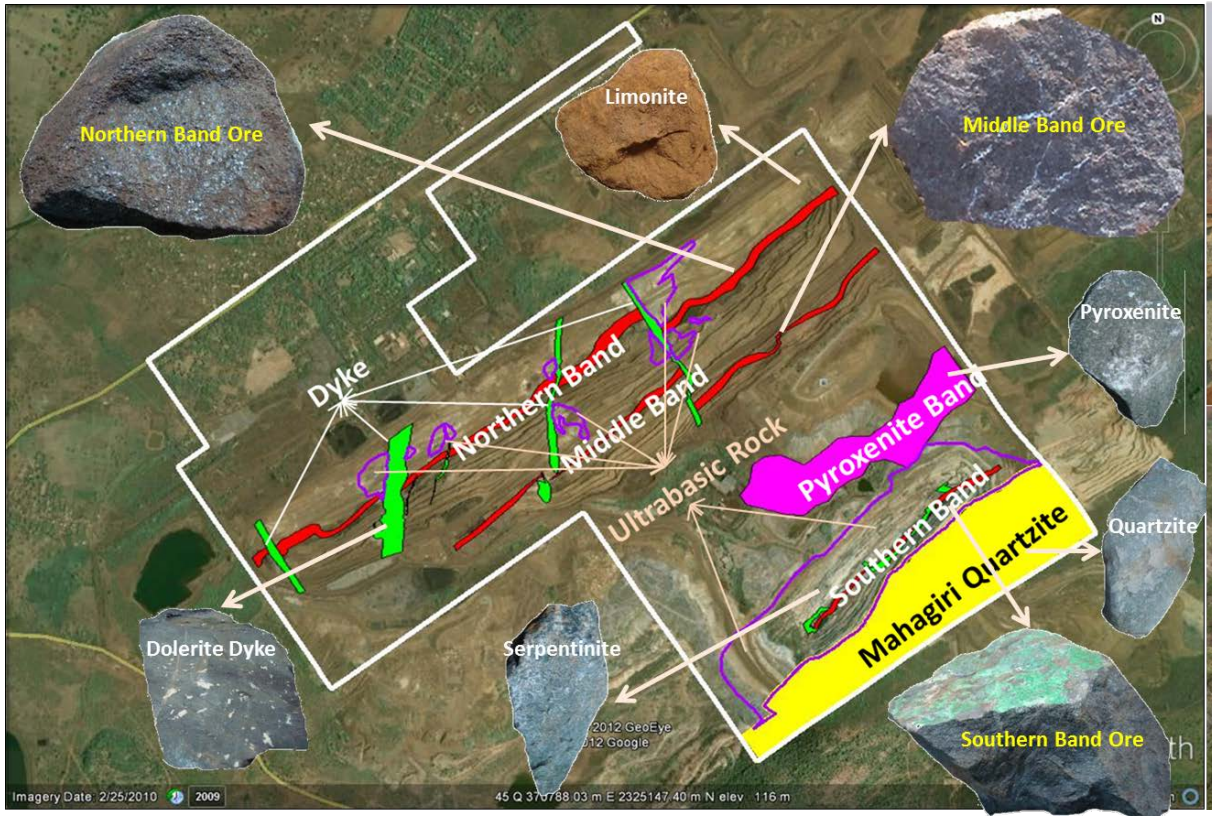
2. SUKINDA CHROMITE MINE: AN OVERVIEW

- Ultramafic hosted stratiform chromite deposit
- Ultramafic rocks mainly comprise of Dunite-Peridotite which have been altered to serpentine-talc-chlorite-magnetite ± magnesite ± sulfides; Process of extensive lateritization/ limonitization at the central part of the valley
- Six chromite bands following the trend of regional synclinal structure

- **Nearest Airport: Bhubaneswar (135km)**
- **Nearest Railway Station: Jajpur Keonjhar Road (55km)**
- **Nearest Port: Paradip Port (155km)**
- **Sukinda valley, situated between Mahagiri & Daitari hill range, hosts more than 95% of chromite resource of our country**
- **Chromite in Sukinda valley was first reported by Tata Steel in 1949**

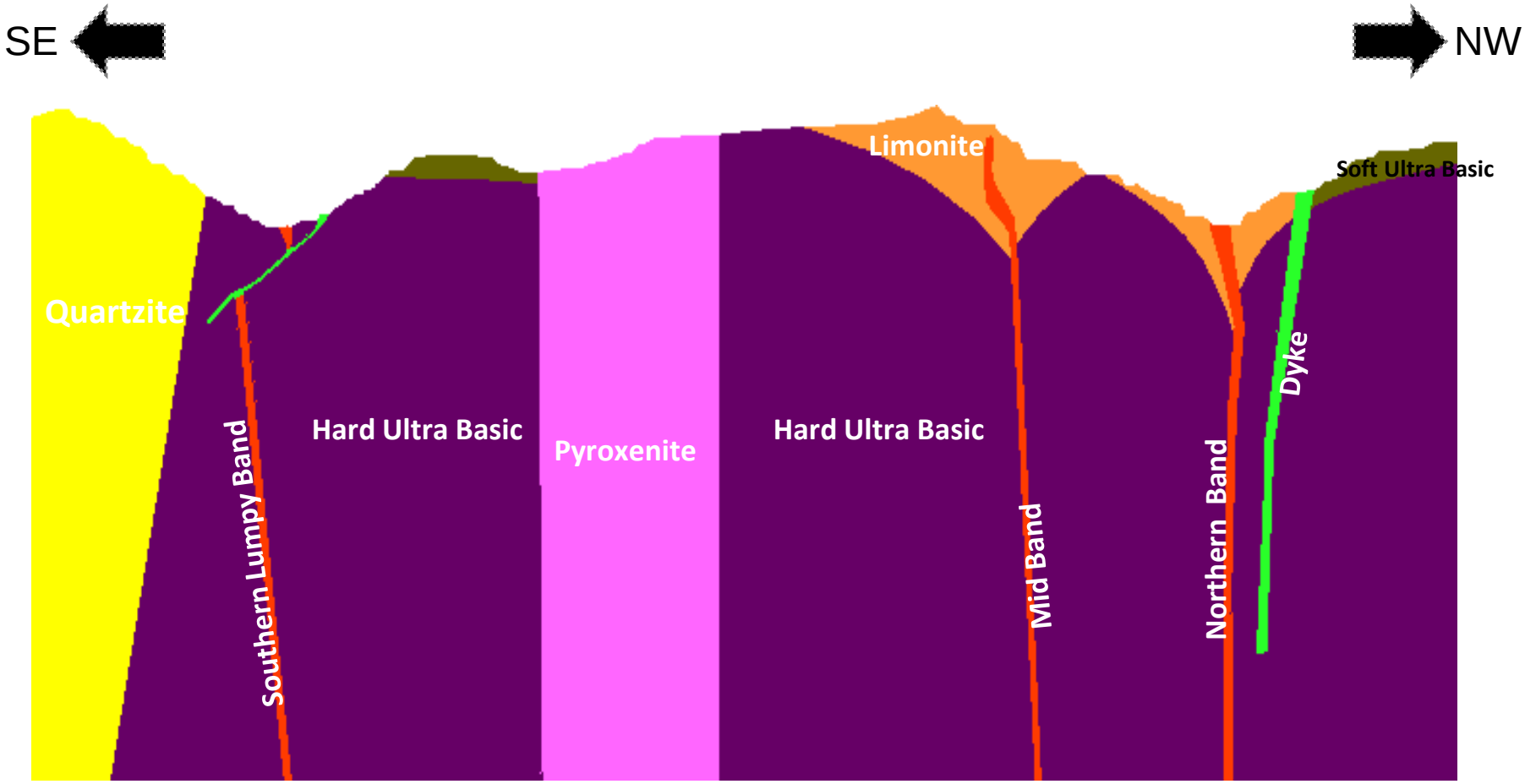


2.1 Geology: Lithology and Mineralisation



- Prevalent **rock types** in the lease area include **Quartzite, Serpentinized Dunite-Peridotite** (**locally known as Hard Ultrabasic or Soft Ultrabasic based on the weathering condition**), **Pyroxenite, Dolerite, Laterite & Limonite with secondary Chert.**
- Two types of ore found within the leasehold area: **FERRUGINOUS** (Northern & Middle Band) & **SILICEOUS** (Southern Band)
- **Northern & Middle Band**: ore bodies weathered; become friable due to removal of binding material as a consequence of weathering.
- **Southern Band**: Noticeable structural disturbances, **but unaffected by weathering**.

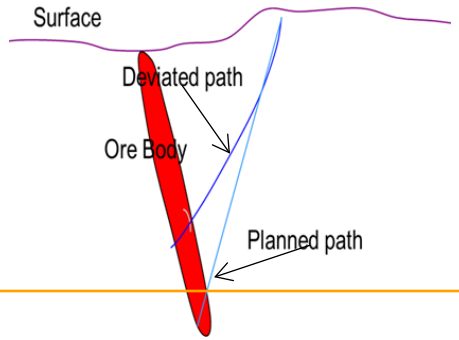
Disposition of Rock Types: Schematic Cross Section View



2.2) Exploration: Strategy, Challenges and Mitigation Measures

STRATEGY ADOPTED:

- Inclined Boreholes drilled to intersect the orebody at different depths **as per UNFC guidelines.**



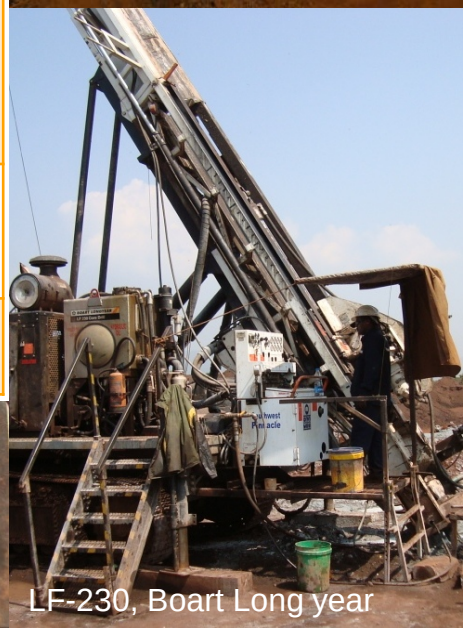
CHALLENGES FACED:

- Drilling in soft, weathered and friable formations
- Frequent hole collapse
- Very low core recovery
- Hole deviation, etc.

MITIGATION MEASURES FOLLOWED:

Enhanced Core Recovery	❖ Selection of ideal mud and polymer ❖ Evaluation of the proportion of bentonite & the polymer to be mixed ❖ Use of triple tube core barrel ❖ Proper selection of drill bit and barrel ❖ Checking of ingredient and chemical constituents of ground water
Enablers for Hole Stabilisation	❖ Evaluation of the proportion of bentonite and the polymer to be mixed ❖ Using quick setting cement liquid like Sika-40 ❖ Using sealing agents (AUS- PLUG by AMC) in the fractured formations ❖ Using Telescopic Drilling
Minimised Hole Deviation	❖ Extra reamer shell on the top of the barrel ❖ Heavy (chrome /flexi barrel)and longer core barrel (6 m) ❖ Digital borehole deviation camera
Monitor the Borehole Path	❖ Digital borehole deviation camera


CS-14, Atlas Copco


LF-230, Boart Long year


Drill Bits


Borehole Deviation Camera

Core Recovery: Pictorial View Before and After Mitigation Measures

Core recovery in soft weathered formation: ***Before***

Core recovery in soft weathered formation: ***After***

Core recovery in Friable ore: ***Before***

*Core recovery in Friable ore :****After***

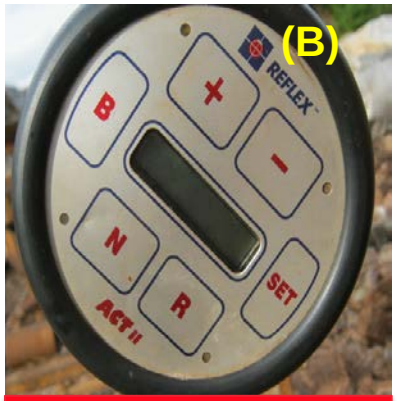
Measurement of Structural Data: Digital Core Orientation Technique

- "**Digital core orientation technique**" has been adopted instead of the Conventional spear mark technique for core orientation.

(A)

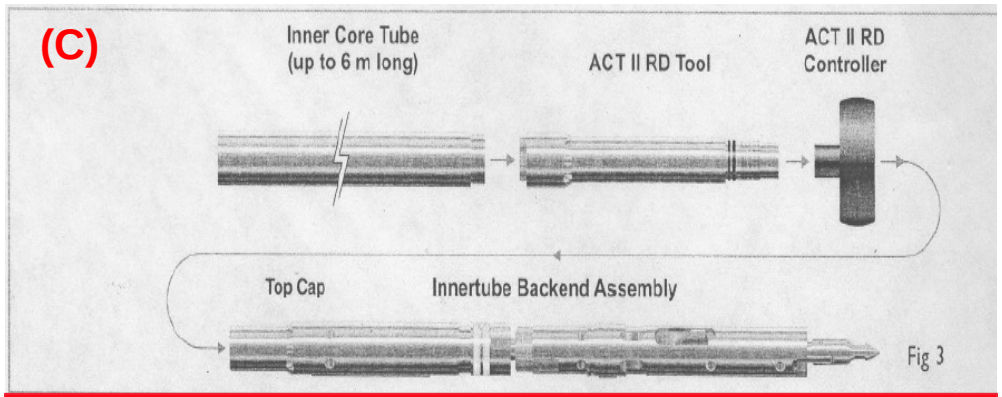
ACT II RD Tool

(B)



ACT II RD Controller

(C)



Fixing the Core orientation tool with Inner tub & Synchronizing

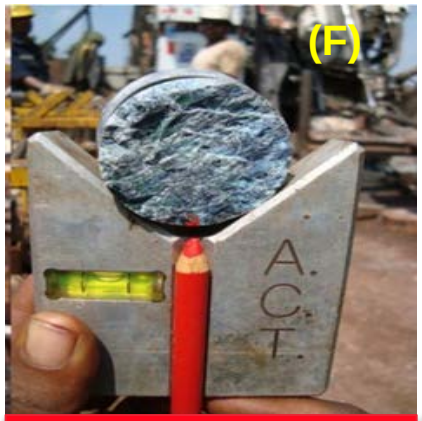
(D)

Inner tube is lowered with orientation tool &Drilling Commences

(E)

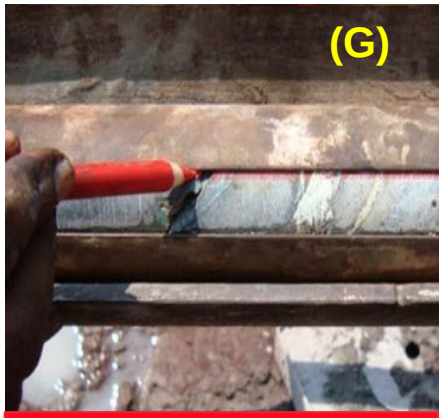
After drilling, Synchronization of the tool and Controller and Realigning

(F)



Placing the Bottom mark on the core

(G)



Marking the Orientation line on the core surface

2.3 Stages of Core Processing :Post drilling activities

- Core Photography
- Core logging & Sampling
- Determination of Specific Gravity
- Core Splitting
- Sample collection and preparation
- Core Storage

1) Core Photography

2) Logging & Sampling

3) Specific Gravity Determination

4) Core Splitting

5) Sample Preparation

6) Core Storage

Core Library

3. QA/QC PRACTICES NEED AND IMPORTANCE

Why QA/QC?

QA/QC procedure in mineral exploration emphasized after the occurrence of 1997 Bre-X gold project scandal and consequent credibility gap in resource classifications.

What is QA/QC?

Canadian Institute of Mining, Metallurgy and Petroleum guide to Best Practice (CIM 2003, p8) states that
Quality Assurance (QA) refers to "All of those planned or systematic actions necessary to provide adequate confidence in the data collection and estimation process."
Quality Control (QC) refers to the use of statistical tools to ensure that the systems are in statistical control.

CIM Best Practice Guidelines (page 12), mentions "QA/QC must be addressed during the collection, recording and storage of any of the data. This programme should be concerned with, but not limited to, data verification, drill sample recovery, sample size, sample preparation, analytical methods, the use of duplicates/blanks/standards, effects of multiple periods of data acquisition and consistency of interpretation in three dimensions. The results of the QA/QC programme form part of the database and must be recorded."

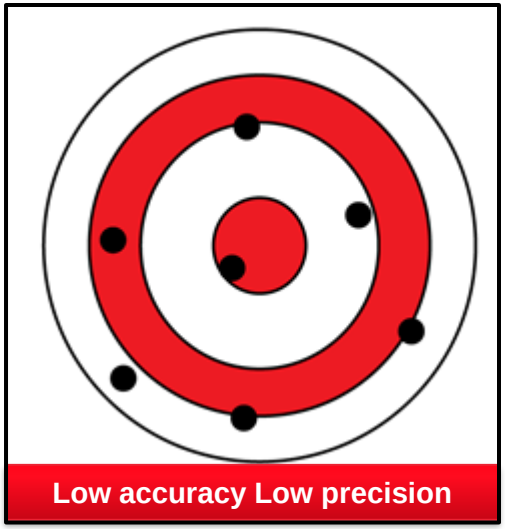
Aspects of QAQC

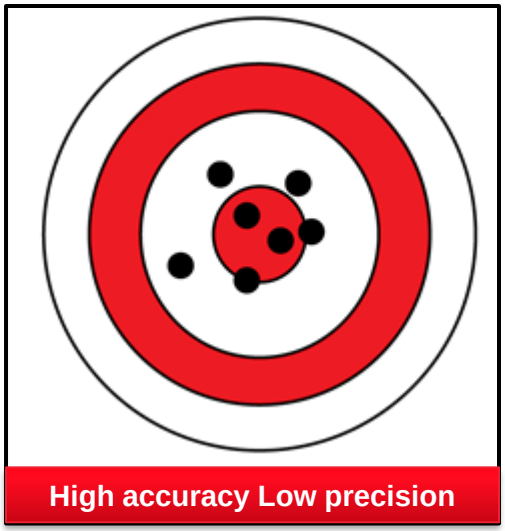
(A) Sampling: Most important aspect of exploration project; evaluation index of exploration; thus important to verify quality and assure accuracy.
Sampling Error occurs due to inherent heterogeneity of sample material; Studies by M/s RPM, Australia suggests sampling errors account for 80% of the total error with sample preparation contributing to further 15% while assaying responsible for the final 5%.

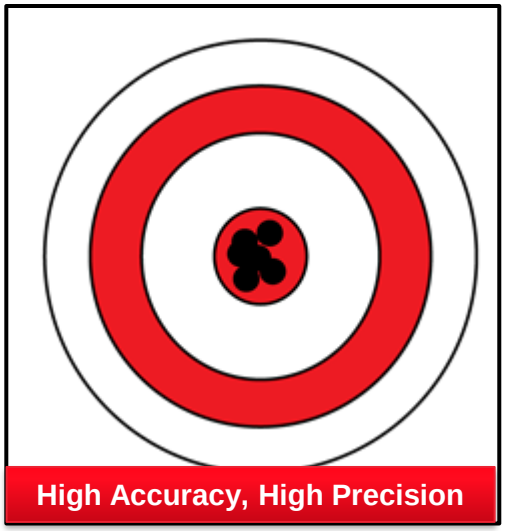
(B) Maintenance of Quality of field data :Precision and Accuracy

Field data quality is assessed on the basis of two types of measure: **Accuracy** and **Precision**.

- Accuracy measures the degree to which an assay represents the true grade of the sample.
- Precision measures the reproducibility of results.







4. QA/QC PRACTICES IMPLEMENTED IN SUKINDA CHROMITE EXPLORATION

QAQC practices maintained in :

I. Drilling

II. Core logging and Core Splitting

III. Sample collection, preparation and analysis

IV. QAQC study and Re-validation of logging

I. Quality Assurance Practices complied in Sukinda Chromite Exploration

a) Pre Drilling :

- The drill collar positions are set out by a surveyor. Pegs are carefully annotated with the proposed hole number and coordinates.
- The drill rigs are set up and aligned with desired inclination & azimuth and it is levelled
- The geologist double-checks the azimuth of the rig using a sighting compass, avoiding contact with any metal equipment anticipating possible interference with the magnetic compass.
- Joint azimuth measurement by geologist and driller is done before starting of Drill Rig.

b) During Drilling:

- Cross-checking of data obtained from deviation survey tool everyday at site. Discussions with driller about any anomaly in deviation of bore hole path.
- Joint measurement of recovery of core for every run by driller and geologist.
- Daily inspection at drill site to monitor progress of drilling.
- Inspection of Core handling at Drill Site and ensuring the down depth arrangement of drilled cores in the core boxes and proper marking on the core indicating the down depth direction and insertion of Tag indicating the run details.
- Careful and professional method of presentation of core on core trays ensured so as to avoid contamination. Incorrect lay down of core will produce unrepresentative samples, therefore adequate care and caution has to be maintained..
- Observance / detection of any substandard practices or poor core presentation, it is brought to the notice of the drill crew and necessary rectifications are made.

c) Post Drilling:

- Final collar Survey by surveyor after finishing of every bore hole. 10-15 %borehole collars are re-surveyed.
- Joint Measurement (JMC) of Drilled Depth.
- On completion of each hole, a survey stake is placed at the collar displaying the hole number and total depth and are marked appropriately on a Concrete Pillar.
- The holes are plugged and covered, or capped ensuring the possibility of re-entry.

**Twin boreholes for cross checking the historical data at Sukinda have not been done as is being done in other locations / commodities in Tata Steel.

II. QA/QC Practices complied in Sukinda Chromite Exploration - Core logging & Core splitting

Core Logging:

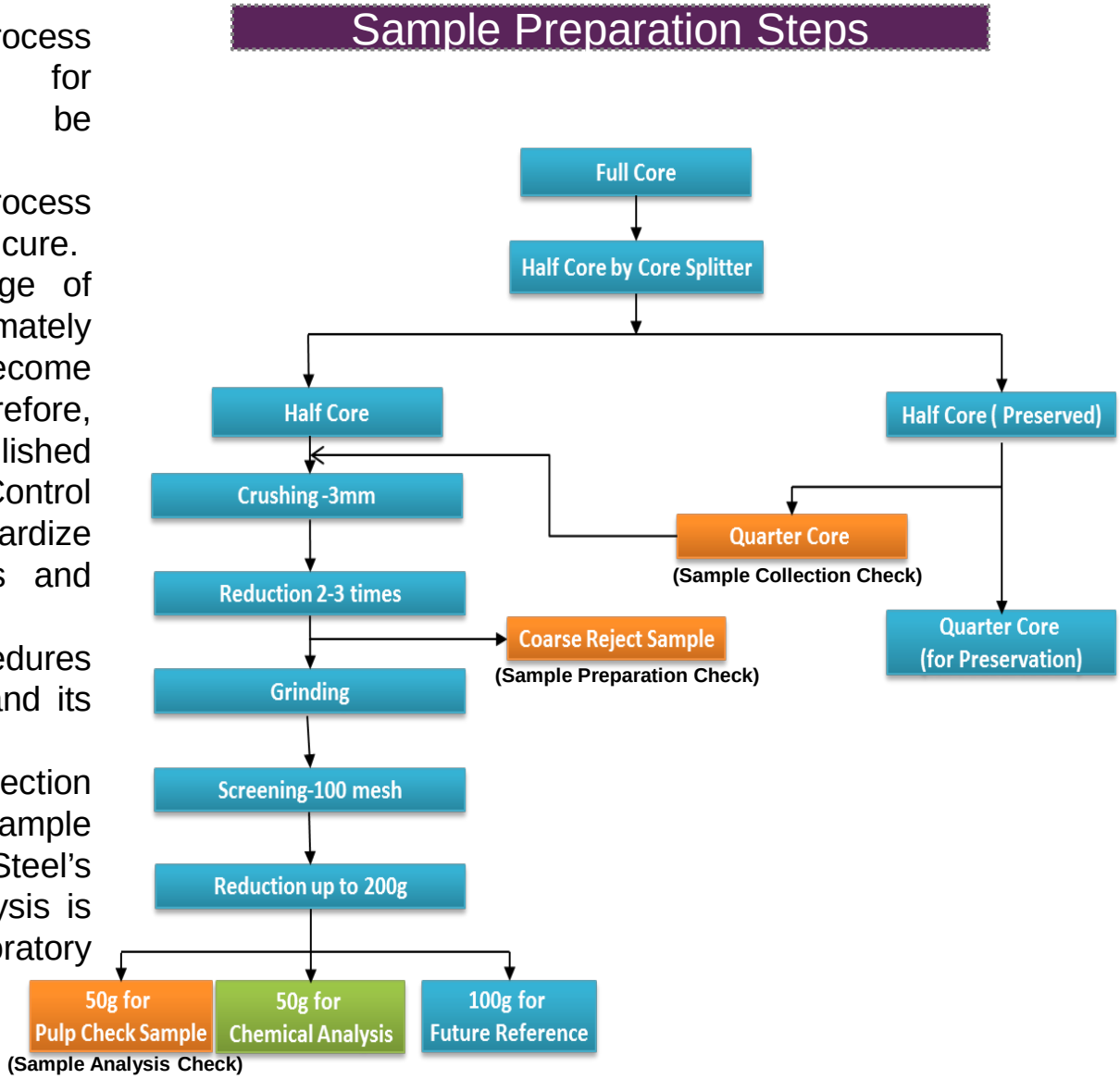
- Core photography done in Standard Light and constant Zoom level.
- A standardized logging form is used to log the core. The form has tabs for Geology, Geotechnical and Sampling (Assay), with columns for each type of information being recorded.
- Structural Core Logging is done based on the Orientation marks and Geological Structures/ Features present on the Core surface.
- Sample marking is done on the Core based on the Logging as well as the **Approved Sampling Protocol** of Sukinda Mines, Tata Steel.
- The core is then marked with a reference line parallel to Core Axis, which symmetrically divides the mineralization in to two halves which is a basis for Core Splitting.

Core Splitting:

- In case of **Intact cylindrical core**, the drill core is split into **symmetrical halves** using a diamond core saw to provide a sample for geochemical analysis.
- After splitting of individual core pieces are placed back in the core box in its original orientation.
- If the core is loose / **highly fractured**, then appropriate manual method is followed for sample splitting.
- Standard operating practices (SOPs) are maintained for Core Splitting.

III. QA/QC Practices in Sukinda Chromite Mines – Sample Collection, Preparation and Analysis

- All data used for the Geological Process and in particular for estimation/reconciliation must be demonstrable reliably.
- All data used for the Geological Process must be validated, accessible and secure.
- Assay data acquired at any stage of exploration or development ultimately determines whether a project will become economically viable to exploit. Therefore, Tata Steel has established Quality Assurance and Quality Control (QA/QC) protocols that standardize procedures for collecting samples and obtaining related information.
- By implementing these QA/QC procedures the resulting data can be verified and its integrity validated.
- The entire process from sample collection to analysis is **in-house effort**. Sample Preparation is done in Tata Steel's Sampling shed and Chemical Analysis is done at our NABL accredited Laboratory at Sukinda.



Different Types of QA/QC Samples Used in Sukinda:

- **Standards or Certified Reference Materials (CRM):** are samples of known or accepted value that are submitted to assess the accuracy of a laboratory. A systematic difference from the expected CRM result indicates a bias within or between assay batches. Standard samples may be purchased commercially or may be prepared internally and it is recommended to submit standards that span the practical range of likely assay values.
- **Blanks** or samples without mineralization are submitted with each batch of samples sent to the laboratory. The blank material is collected from a location known to be devoid of any mineralization or purchased from a reputed supplier. Results from these samples indicates any contamination introduced during the sample preparation or analysis procedures.
- **Pulp Duplicate/ Check:** These samples are the identical pulp samples collected at the final stage of sample reduction. Generally, Check samples are the identical pulp samples of previously analyzed sample.
- **Field Splits/Duplicate** are samples collected, prepared and assayed in an identical manner to an original sample collected and submitted to provide a measure of the total variance introduced by the entire sampling and assaying process (precision).
- Different kinds of Duplicate samples used at Sukinda are described as below:
  - ✓ **Coarse Reject Duplicate (CRD)** are collected by taking a second split after crushing, before the pulverizing stage. These samples are sent to the same laboratory at a later stage. The assay of the coarse reject samples has been compared with the assay of the half core (original assay).
  - ✓ **Quarter Core Sample:** The remaining core (half-core) after splitting is re-split (quarter-core) and submitted as a duplicate sample to the laboratory.
- **Umpire Check Samples:** Umpire assays check the analytical precision of the laboratory relative to an umpire laboratory. (Check assaying through an umpire laboratory does not determine which laboratory is more accurate). Pulp samples from the primary laboratory are retrieved and submitted as a batch to the umpire laboratory for analysis. The selection of the umpire laboratory is done after ensuring that it uses an assaying technique identical to the principal laboratory.

QA/QC Protocol followed in Sukinda:

- All exploration samples are analyzed at Sukinda laboratory by ICP-AES (NABL Accredited)
- As a part of comprehensive QA/QC program for exploratory sample analysis, the below steps followed heeding to suggestions made by M/s SRK Consultants, South Africa
  a) Sample Preparation is done at Sampling shed, Sukinda under the Supervision of geologist in-charge.
  b) Ideally each batch of Samples are sent to Chemical Laboratory contains 30 Samples (25 Half core samples and 5 QA/QC Samples)
  c) QA/QC samples are inserted randomly (decided by the Geologist) and sent to the Lab along with the Half core pulps with identical sample number in sequence.
  d) Details of the QA/QC samples are never communicated to the Lab.
- Details of the Individual Sample Batch is given in tabular form:

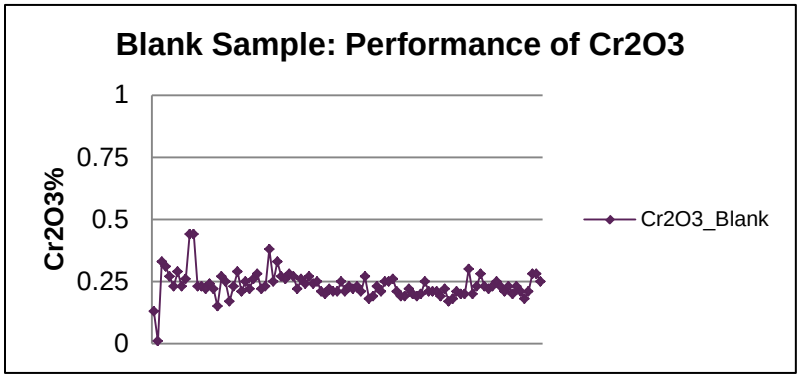
Sample type in a single batch	No of Samples
Original sample (unknown)	25
Blank sample	1
Certified Reference Material (CRM)	1
Check of previously analyzed sample	3
Total	30

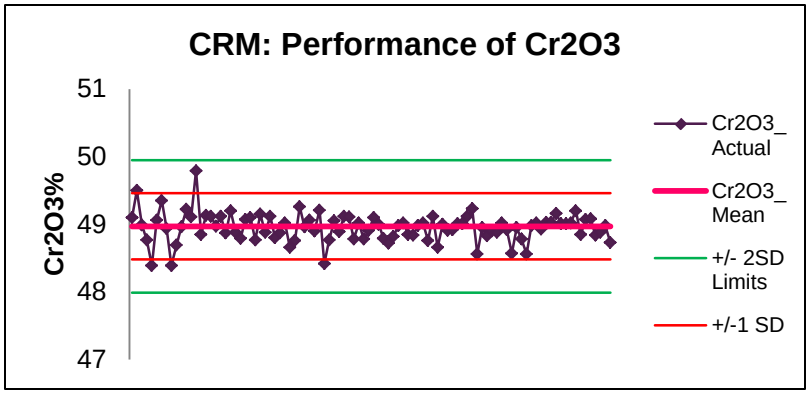
- Quarter core and Coarse Reject samples are sent to Laboratory periodically in separate batches covering the entire Grade range of the Chromite Ore.
- Approximately 10% of the exploration samples are periodically sent to an Umpire laboratory to check the precision and accuracy of the Original Laboratory.
- In addition, sizing Checks are carried out at the Sampling Shed @ 1 in 30 samples.

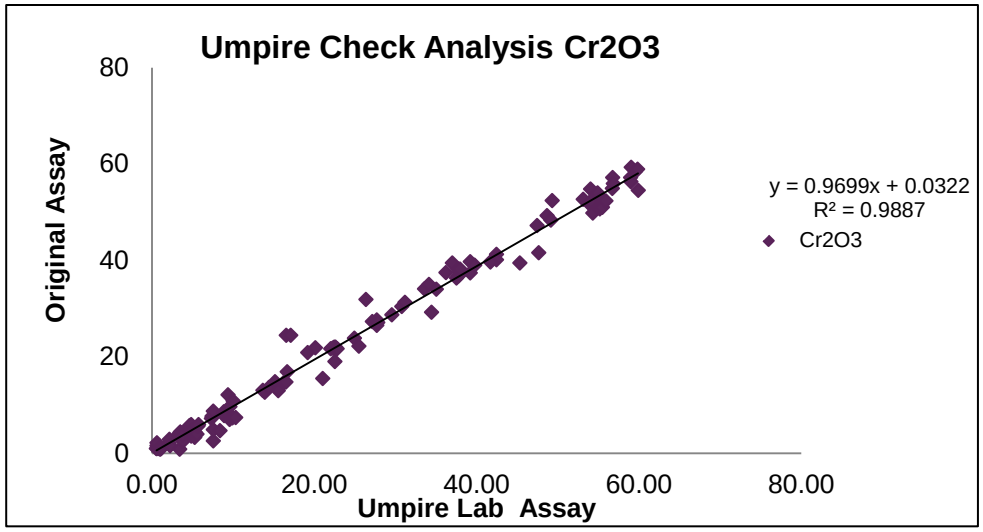
QA/QC Performance of Sukinda Chromite Mines Exploration

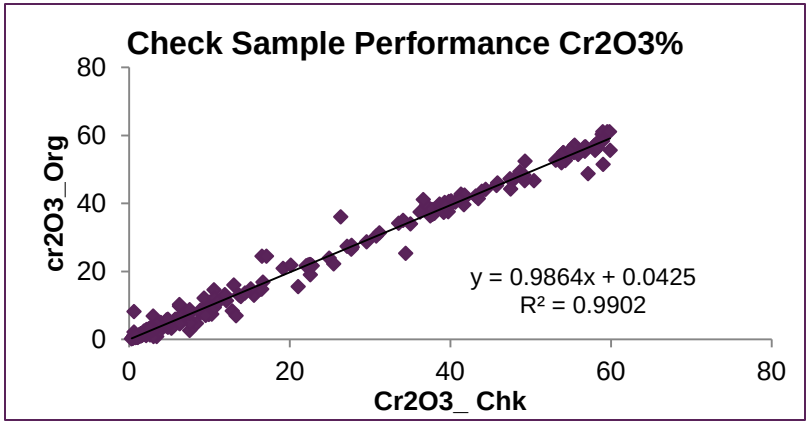
QAQC Analysis: Acceptance Criteria

Sample Type	Parameter Checked	Acceptance	Rejection
Blank sample	Maximum %	<0.5% Cr2O3%	>0.5% Cr2O3
Certified Reference Material (CRM)	Matched against the Mean value of the CRM Certificate	< 2SD **(<1SD is Desirable)**	>2SD
Check Sample	Value Matched against the Original Assayed value	R^2 >95%	R^2 < 95%
Quarter Core		R^2 >95%	R^2 < 95%
Coarse Reject		R^2 >95%	R^2 < 95%
Umpire Check		R^2 >95%	R^2 < 95%
Sizing Check	% passing through Screen/Sieve	>90% Pass	< 90% Pass

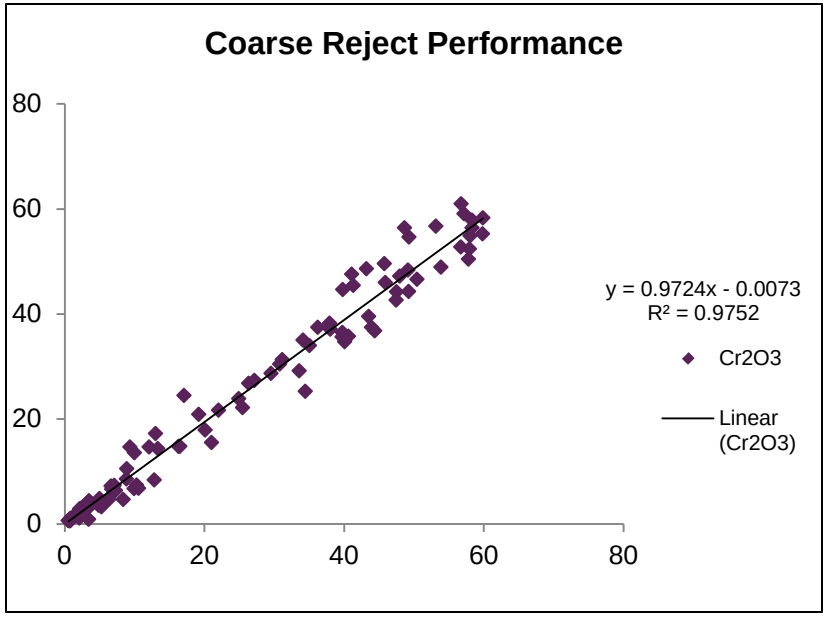


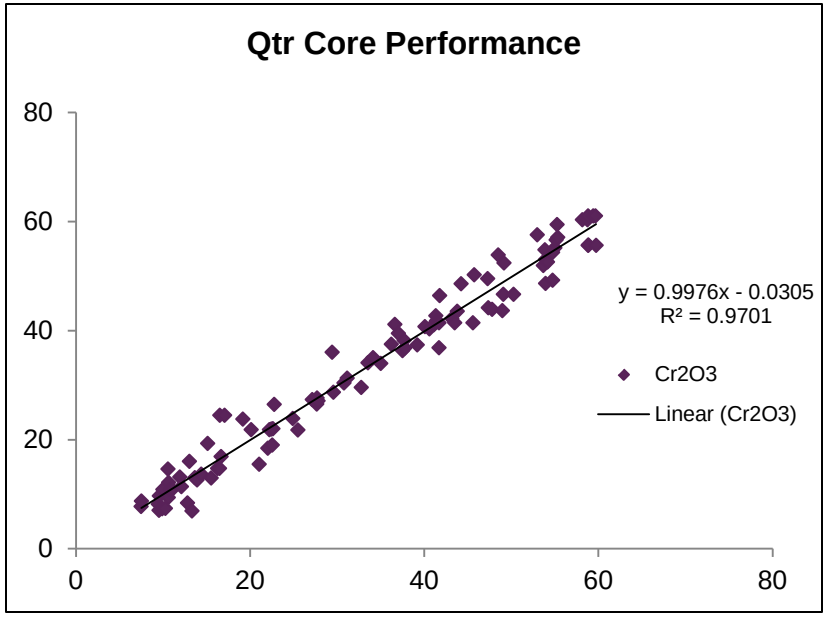






QA/QC Performance of Sukinda Chromite Mines Exploration……contd.





- Blank Sample: All the Blank Samples are analysed with <0.5% Cr2O3; the acceptable limit according to the QA/QC protocol.
- CRM Samples: All the CRM Samples analysed are within the range of 2 Standard Deviation.
- Pulp Duplicate/ Check Samples: Gives a good correlation with the original Assay (R^2- >99%)
- Coarse Reject Samples & Quarter core Sample: show good correlation with Original Assay (R^2- >97%)

****The graphical representation for QAQC performance has been shown for Cr2O3 only; although similar practices are followed for other radicals like Fe, SiO2, Al2O3 etc.**

IV. QA/QC Practices in Sukinda Chromite Exploration - Re-validation of logging & Documentation of Data

- Verification of significant intersections is done by competent higher authority.

- Lithology and the mineralization details observed visually is compared with the analytical data. It is accepted if it matches with the analysis; In case of a mis-match, sampling processes reviewed for detection of possible analytical errors. Re-sampling / re-analysis of already prepared pulp or duplicate is done if necessary.

- Based on QA/QC analysis and re-validation of Logging, analysis data is rejected / accepted. Acceptance / rejection of analysis data is done on the basis of QA/QC studies and revalidation of logging. we accept/Reject the Analysis data.

- Documentation of primary data, Data verification and data storage.

5. CONCLUSION

- Quality Assurance practices are followed for prevention of problems, while Quality Control aims for detection of problems as they arise.
- Quality Control practices involves the use of statistical tools to monitor contamination, accuracy, precision and bias.
- Effective QA/QC programme is one that is active and is reviewed throughout the data collection process, enabling corrective action to be taken.
- QC sample populations can be readily described and interpreted using graphical techniques, in addition to classical statistical methods.
- The use of standard (CRM), blank, duplicate and check samples according to modern best-practice QC procedures adds value to any mineral exploration programmes, whether or not mandated by any reporting code
- More than compliance with any particular code prescribed world-wide, the control of data quality plays a greater role in decision making. Observance of professional standards with equal emphasis on quality contributes to decision making.
- Regular Lab spot checks with little or no warning and constant monitoring helps in maintenance of quality of data.
- For generation of meaningful / useful data, it is important to obtain representative samples while retaining their integrity. .
- Sampling principles should be strictly adhered to overcome the limitation of emerging biases and imprecision in the input data.

References:

1. *Quality control and public reporting in industrial minerals by Andrew Scogings*, **IM** Correspondent, Jacqui Coombes** Sept-2014*
2. https://www.canadamines.ca/sampling101qualityassurancequalitycontrolqaqc/
3. Quality Control and Quality Assurance Programmes: A Priority, Not an Afterthought **Micon International**

Thank you

Abstract of Approved Sampling Protocol

- Following procedure was adopted for sampling of bore holes in Sukinda:
  - The limonitic / lateritic portion of all the holes were completely sampled and analysed for every 5 m i.e. 0 to 5 m, 5 to 10 m etc.
  - Only few selected holes were completely analysed. The top lateritic / limonitic portion were sampled as described as above followed by the soft and hard ultrabasics, which were sampled and analysed for every 10 m, i.e. 20 to 30 m, 30 to 40 m etc.
  - In all the holes the ore zone along with hanging and footwall were sampled and analysed for maximum length not exceeding 1 m.
- Both the hanging wall and footwall of the mineralisation were sampled for minimum twenty five meters on either side. The minimum sample length was not less than fifty cm in order to have ample sample powder.
- Normally sample length was of one-meter length. However, particular care was taken in the ore zone contacts. In the beginning of ore zone the sample started exactly from the contact. Similarly the sample of the footwall contact also ended at that contact. For e.g. if in any hole the mineralisation starts from 250 m the samples were made minimum twenty five meter prior to that i.e. say 225 m. From 225 to 245m, two-meter samples were made and after that from 245m, the samples were made for every one-meter until it reaches 250 m.
- Similar sampling procedure was followed after the end of mineralization, i.e., 5m zone with 1m sample interval, followed by 2m sample interval for next 20m. This was done in order to avoid dilution of grade with hanging wall / footwall and hence we can know the actual geological grade of the zone.

Done as advised by SRK Consulting, G1 IBM-UNFC Unified, SAMREC CODE T3.1, JORC Table 1: Sampling Techniques and Data, Sub-sampling techniques and sample preparation