Developing Integrated Mine Plans

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Introduction

- This presentation will discuss:
  - Level of mine plans required.
  - Tasks required for the development of a mine plan for your site.
  - Informed mine planning provides sustainable management and maximizing of geological resources safely throughout the life of the quarry operation.
  - An integrated mine plan also enables ongoing reclamation of your site to meet environmental and planning permit conditions.
  - This education session will be based on real life examples from both sand & gravel and crushed stone quarries.

This Granite Quarry has been developed as a "Top-Down" quarry which has involved the mining of a large part of the hillside.
Benefits of a Robust Geological Model and Mine Plan

- Improves geological confidence to understand and manage variations in structure and quality
- Maximizes resource recovery
- Optimizes waste removal
- Enables design of pit access and ramp systems for life of quarry
- Enables production planning to achieve product blend requirements
- Allows location of facilities to be optimized
- Permits control of CAPEX and OPEX to maximize profitability
- Assists in maintaining regulatory compliance
- Provides technical support for project and/or CAPEX financing
- Provides support to sales and marketing by assuring product meets specifications
- Allows for ongoing reclamation to be planned and accomplished

Developing Integrated Mine Plans

Framing

- How well do you know your site now and in the future?
- What level of mine plan is required?
  - ~ 75% of sites there is no mine plan
  - Small, single bench deposits
  - Little or no variation in quality
  - Above water-table
  - No blasting (sand & gravel)

- Risks of having poor or no mine plan?
  - Deposit complexity
  - Variation in quality
  - Resource sterilization
  - High grading
  - Slope stability
  - Water management
  - Stripping ratio
  - Reclamation – after use
  - Change in personnel/management

- How well DO you know your site?!
Developing Integrated Mine Plans

Presentation will be divided into 2 parts:

- Determine the complexity of a Mining Plan (from BASIC to more COMPLEX)
- Case Studies

**TASKS** – to determine the complexity of a Mining Plan

**Basic Mining Plan**
- Task 1 - Desk Top Review (Gap Analysis)
- Task 2 - Site Visit

**More Complex Mining Plan**
- Task 3 - Geological Model
- Task 4 – Mine Plan Design
- Task 5 - Resource Estimation
- Task 6 - Mine/Quarry Development Plan - Sequencing

**Note:** Various Guidelines such as H&S, Environmental, Geotechnical, Permitting and EA should be consulted and ‘built into’ the quarry design and extraction/reclamation plan for your site from the start.

For example: NSSGA has produced a guide for members on presence or absence of asbestiform minerals on your sites and presents potential actions to take if such minerals are found:

[Minerals Identification and Management Guide](#)
### Basic Plan - Task 1: Desk Top Review (‘Gap Analysis’)

- Review all available data
  - **Plans**
    - Base – topography, satellite, aerial, environment
    - License boundary
    - Geology – soils, overburden, bedrock
  - **Digital Files**
    - Drilling
    - Sample data
    - Survey data - mapping
  - **Reports**
    - Permit conditions (Planning – EIA)
    - Geology
    - Geophysics
    - Resource
    - Geotechnical
    - Hydrogeology - Hydrology
    - Production data

**DESK TOP REVIEW REPORT** – may be enough, if not go to Task 2 and so on

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### Basic Plan - Task 2: Site Visit

- **Geology**
  - Meet with Site personnel
  - Review drilling & sampling practices
  - View ‘core’ & sampling storage areas
  - Visit analytical laboratory
  - Collect additional information
  - Photographs
- **Geotechnical**
  - Mapping – collect field data on discontinuities
  - Discuss development planning issues and concerns
  - Photographs
- **Hydrogeology (& Hydrology)**
  - Groundwater & surface water management
  - Discuss development planning issues and concerns (drawdown, run-off, discharge)
- **Operational Procedures**
  - Discuss current design, extraction plans & practices
  - Review both fixed & mobile plant
  - Manpower
  - Pumping
  - Costs

**Site Visit Report with Desk Top Review Report – Development of Basic Mining Plan**
Site Visit - Existing Conditions (Basic Plan)

- Active extraction
- Plant site
- Waste

Future Extraction

Houses

300m

Base maps (including aerial photographs)
- Permit – license boundary
- Permit – license conditions
- Up to date 3D topographical survey (x,y,z)
- Geology (from Tasks 1 & 2)
  - Mapping
  - Borehole & trial pit logs and photographs
  - Sampling data (quality)
- Geophysics (e.g. ERI, Seismic Refraction, EM31) follow-up with intrusive investigation
- Hydrogeology (from Tasks 1 & 2)
  - Water-table (pumping test)
  - Watershed / Catchment size
  - Rainfall data
- Geotechnical (complete assessment) (from Tasks 1 & 2)
  - Mapping discontinuities
  - Borehole & trial pit information

ROBUST 3D GEOLOGICAL MODEL
Up to date 3D topographical survey
- Base maps
- Permit – license boundary
- Permit – license conditions (e.g. hours of operation, emission, limits, traffic, water, reclamation)
- Geological Model (from Task 3)
- Geotechnical Assessment (from Task 3)
- Hydrogeology/Hydrology (from Task 3)
- Economic factors
  - Expected production rates – market conditions
  - Stripping ratios, Haulage distances
  - Cost estimates
    - CAPEX
      - Fixed Plant & Mobile Plant
    - OPEX
      - Labor
      - Power & Fuel
      - Explosives
Complex Plan - Quarry/Pit Design

Slope angles from modelling of geotechnical mapping and borehole information

Complex Plan - Task 5: Resource Estimation

Use Geological Model (from Task 3) to produce Resource Estimation
- Up to date 3D topographical survey
- Validated drill hole database
  - Collar
  - Survey
  - Geology
  - Sample data from certified laboratory
  - SG
- Variography – (geostatistics)
- Block model

RESOURCE ESTIMATION MODEL (can be used for)
- Scoping Studies
- Feasibility Studies
- Financing Studies
- SEC Information Guide 7 / NI 43-101 / JORC Reporting
- Mergers & Acquisitions
Complex Plan - Resource Block Model Estimation

- Block Model

Complex Plan - Task 6: Quarry Plan

- 3D Layout with ramps, haul routes, benches, stockpiles, sumps, silt ponds, crusher, conveyor etc.

- Phasing sequence for mine plan (Tasks 4 & 5)

- Blending schedule for each mine plan phase
  - Stockpile management plan

- Final quarry slopes & optimal quarry limits

- Identification of new areas for extension drilling

- Progressive & final reclamation (after-use)

QUARRY DEVELOPMENT PLAN (Scheduling & Blending)
Complex Plan - Quarry Stage Design Example

Complex Plan – Mine Plan Sequencing/Phasing Example
Complex Plan - Final Quarry Design

- Reclamation planning and phasing
- Biodiversity enhancement
- Aftercare planning and vegetation establishment

Complex Plan - Final Reclamation Example
Pulling it all together

Case Studies

- Case Study 1 - Glacial Sand & Gravel for Aggregates and Ready-Mix Concrete
- Case Study 2 - Limestone for Power Station Desulfurization Material (DSM)
- Case Study 3 - Underground Quarry for Limestone Aggregate
- Case Study 4 - Limestone for Cement Kiln and Aggregate Production
Case Study 1
Sand & Gravel Quarry

Glacial Sand & Gravel for Aggregates & Ready-Mix Concrete

Glacial Sand & Gravel for Aggregates (1a)
Glacial Sand & Gravel for Aggregates (1b)

Rabbit Sand Dominant Unit
Fine Sand Dominant Unit
Sand & Gravel Dominant Unit

Glacial Sand & Gravel for Aggregates (2)

Rabbit Sand Dominant Unit
Fine Sand Dominant Unit
Sand & Gravel Dominant Unit
Glacial Sand & Gravel for Aggregates (3a)

- Site known to be part of a large complex moraine deposit
- Initial estimates of tonnage using standard drilling techniques ~ 16 million tonnes
- Operator started to excavate football field size area – silt and clay encountered – over $250k spent

Glacial Sand & Gravel for Aggregates (3b)

- Used combination of ERI lines and drilling of ‘targets’ to re-evaluate the resource
- New tonnage estimate for the site was found to be 4 million tonnes – prompted owner to start looking for new resources sooner than planned

Quote from operator of site:

“I use that 3D figure you provided as my mining plan and where you show the resource should be, it is there!”
Case Study 2  
Limestone Quarry Exploration Program, Geological Model and Extraction Plan  
For Power Station Flue Gas Desulfurization

<table>
<thead>
<tr>
<th>Limestone for Power Station - Objectives and Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Purpose / Objective</strong></td>
</tr>
<tr>
<td>- Phase 1 – Evaluate potential quarry properties, develop an exploration program and select quarry site for limestone desulfurization material (DSM) supply to the power plant</td>
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<tr>
<td>- Phase 2 – Evaluate property for feasibility-level quarry design, production plan and cost projections</td>
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</tbody>
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<table>
<thead>
<tr>
<th>Key Limestone Grade Requirements and Resource Tonnage</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Calcium Carbonate (CaCO₃) &gt; 90.0% for DSM</td>
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<tr>
<td>- 40-year quarry life at 1 million ton per year (Mtpy)</td>
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<th>Property Requirements</th>
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<td>- Within reasonable proximity of the power station</td>
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<td>- Potentially acquirable</td>
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<td>- Reasonable expectation of permitting success</td>
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<td>- Competitive production and capital costs</td>
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</tbody>
</table>
Phase 1 Exploration Programs
- Six potential properties
- Prioritized 4 drilling programs over 18 months
- Forty-two 4-inch boreholes using sonic drilling rig
- 555 samples analyzed for chemical and physical properties
  - Samples at nominal 5 feet lengths (adjusted for lithology)
    - Chemical analysis
    - Loss on ignition (LOI)
    - Insoluble residue
    - Rock density
    - Limestone reactivity
    - Bond Work Index (BWI)
  
Limestone for Power Station - Phase 1 Exploration Geology

Models created utilizing Minescape™ software

Structural Models (25-feet grid cell size)
- Surface topography using USGS Digital Elevation Model (DEM) data
- Roof and floor structure grids from down-hole core intercepts for:
  - Calcareous clay unit overlying limestone formation
  - Limestone formation

Quality Block Models
- Blocks 100 ft x 100 ft x 5 ft in height
- Limestone quality analyses interpolated into blocks for key constituents:
  - Calcium Carbonate (CaCO₃)
  - Calcium Oxide (CaO)
  - Iron Oxide (Fe₂O₃)
  - Magnesium (Mg)
  - Elemental Sulfur (S)
Limestone for Power Station - Phase 1 Results

- Preferred property
  - Highest rank and least risk
  - 600 Mt of limestone
  - 94% average CaCO$_3$

- Pit layout
  - 11 sub-pits to minimize groundwater pumping and off-site draw-down
  - 90 Mt of resource
  - 95% average CaCO$_3$

- Developed pro forma production and capital cost estimate

Phase 1 – 21 month process

Based on the Phase 1 results, client purchased preferred property and initiated Phase 2

Limestone for Power Station - Phase 2 Scope

- Conduct feasibility-level exploration and testing program to improve geological confidence
- Complete hydrogeological investigation and groundwater model
- Update geological model
- Update resource estimates
- Develop pit layouts and quarry pit designs to consider:
  - Maximization of reserves
  - Surface and sub-surface hydrological and environmental constraints

- Estimate quarry reserves
- Select equipment and estimate productivity
- Develop annual production plan schedule for a 40-year quarry life (at 1.0 Mtpy)
- Estimate limestone production and capital costs
Geological Exploration Program
- 6 sonic / 7 diamond bit core holes
- 277 samples analyzed
  - Chemical analysis
  - Loss on ignition (LOI)
  - Insoluble residue
  - Specific gravity and porosity
  - Limestone reactivity
  - Compressive strength & BWI

Hydrogeological Exploration Program
- 13 deep / 2 shallow monitoring wells & 1 pumping well
- Pumping tests and groundwater modeling

Limestone for Power Station - Phase 2 Geological Structure Model
- 31 drill holes modeled
- Structural model - 25’ x 25’ grid cell spacing
  - Topography from USGS DEM data
  - Roof and floor structure grids created from bore hole intercepts
    - Clay unit overlying limestone
    - Limestone formation
  - Overburden - topography to clay roof
  - Limestone floor marked by basal shale
- Unconsolidated overburden thickness: 15’ – 30’
- Clay thickness: 0’ – 11’
- Limestone unit thickness: 7’ – 94’
- Stripping ratio: 0.15 bcy/ton to 0.35 bcy/ton
**Limestone for Power Station - Phase 2 Structural Model**

- Block models developed using blocks of 50 ft x 50 ft x 1 ft in height
- 454 quality samples utilized from Phase 1 and 2 drilling programs within property
- Limestone down-hole quality analyses interpolated into blocks for key constituents:
  - CaCO₃
  - CaO
  - Fe₂O₃
  - Mg
  - S
  - Relative Density

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**Limestone for Power Station - Phase 2 Quality Block Model**

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Limestone for Power Station - Phase 2 Quarry Layout & Mining Plan Criteria

- Limiting buffers:
  - East property boundary = 250’
  - North, South, West = 100’
  - Transmission line structure = 150’ with a 20’ wide access connecting structures
- 50’ bench width at top of limestone and mid-depth
- 25° overburden slope angle
- 80° pit wall angle
- 5’ bench height
- Royalty area extents, costs and term
- Wetlands disturbance impacts
- Stripping ratio
- Pit length for face development
- Facilities and infrastructure locations
- Hydrogeological constraints

- DSM specifications:
  - CaCO₃ >= 90.0%
  - Fe₂O₃ <= 0.92%
  - CaO >= 48.5%
  - MgO <= 0.8%
  - Sulfur <= 0.3%

- Crushed DSM product size = minus ½”

- Preferred DSM size distribution:
  - 65% - 85% passing # 4 screen
  - 55% - 75% passing # 10 screen
  - 35% - 55% passing # 30 screen
  - 0% - 30% passing # 200 screen

Limestone for Power Station - Phase 2 Relative Cost Ranking & Ultimate Pit

- Developed a relative cost map to identify lowest cost reserves based on:
  - $/bcy waste stripping
  - $/ton DSM loading and hauling
  - $/acre wetland mitigation cost
  - $/ton royalty rate
  - Cost of transmission line relocation

- Ultimate quarry limits and facilities location based on:
  - Surface constraints (wetlands, transmission line, property boundary, nearby residents, access, etc.)
  - Overburden depth
  - Limestone quality
  - Hydrogeological designs (including recharge trench requirements)
  - Relative cost ranking
Limestone for Power Station - Phase 2 Pit Layout & Mining Plan

- Designed 11 sub-pits to:
  - Quantify sufficient DSM tonnage for 40-year production plan
  - Minimize impacts to off-site ground water drawdown
  - Minimize pit dewatering requirements
  - Incorporated groundwater recharge trench designs to minimize groundwater drawdown impacts to nearby residents
  - Minimize costs and delay mining progression into royalty area

- Target limestone reserve estimates of 130 Mt at an average CaCO$_3$ content of 94%

Limestone for Power Station - Phase 2 Quarry Mining Sequence

- Developed 40-year production sequence at an annual DSM rate of 1.0 Mtpy

- Quarry plan production
  - 40 Mt of limestone DSM
  - 0.30 bcy/DSM ton average stripping ratio
  - 94% average CaCO$_3$

- Estimated quarry production costs and capital requirements
Case Study 3
Underground Limestone Quarry Development Plan
For Concrete Aggregate Production

Objectives
- Define UG limestone resource through exploration, analysis, and modeling
- Design development plan to transition from surface to UG operation
- Develop UG access and layout designs
- Development plan sufficient to support regulatory permitting and zoning requirements
- Cost and capital projections of UG plan for overall business plan

Resource Tonnage Requirements
- Produce 1 Mtpy
Limestone Underground (UG) - Study Scope

- Desktop review and site visit of existing operations
- Recommended additional work needed for preliminary UG design
  - 5 core holes
  - Create geological model
  - Rock mechanics testing program for roof and pillar designs
- Create preliminary development plan to include:
  - UG layout and portal designs
  - Production methods and equipment selection
  - Preliminary roof and rib support designs
  - Preliminary ventilation designs
  - Production scheduling and staffing
  - Estimate UG operating and capital costs

Limestone Underground (UG) - Exploration Geology

- Target limestone thickness: 85’ – 100’
- 11 existing core holes in UG mine area
  - Only 1 hole achieved full penetration of target limestone unit
- 8 full-depth core holes proposed to:
  - Define limestone extent
  - Define limestone roof and floor
  - Acquire cores for rock strength analysis
- 5 core holes completed due to time and cost constraints
  - Located core holes to maximize coverage within immediate UG areas
  - Incorporate previous drilling data
Limestone Underground (UG) - *Exploration Geology*

- Model grids created using Carlson software
- Topography modeled using aerial flyover DEM data
- Limestone roof and floor grids utilized information from 16 core holes
- Quarry limits based on:
  - modeled limestone roof outcrop
  - property boundary
  - other limiting information
- Limestone quality
  - UG roof designed to coincide approximately with the low-quality cutoff horizon (top 30’)
  - Quality not modeled (outside project scope)
- Estimated in-place resources based on geological model and quarry boundary extents
Four potential hazards to UG operations identified and assessed

- Solution cavities
- Upper limestone formation replacement with shale
- Vertical joint frequency and condition
- Surface lakes
Limestone Underground (UG) - Rock Mechanics Analysis

- Rock mechanic testing and analyses conducted
  - Uniaxial Compressive Strength
  - Tensile Strength
  - Point Load Index Test

- Testing and analyses results analyzed and used for portal, roof and pillar designs

Limestone Underground (UG) - Preliminary UG Layout

- Room-and-pillar, two-bench operation
  - Top bench developed in advance of bottom bench
  - Benches interconnected in most areas of the UG operation
  - Conservative UG roof thickness of ~ 30’
  - UG floor limestone thickness of ~ 5’ (minimum)

- UG Projections / Plan Layout
  - Projections designed on 60’ by 60’ entry centerlines
  - Entry widths and pillar dimension varied by entry purpose and bench
  - Top bench entries and crosscuts 25’ high by 40’ wide
  - Bottom bench entries and crosscuts 30’ high by 35’ wide on 60-foot centers
Limestone Underground (UG) - Preliminary UG Development Plan

- Preliminary development plan included:
  - Upper and Lower bench development and UG advance
  - Design and scheduling of production unit operations
  - Pillar design
  - UG ventilation designs
  - Surface incoming power and underground power distribution design
  - Portal design
  - Portal highwall protection
  - Quarry life production scheduling
Limestone Underground (UG) - **UG Production Sequence**

Limestone Underground (UG) - **Underground Quarry Installation**

Underground Quarry Upper and Lower Bench Portals (UG layout implemented)
Case Study 4- Limestone Quarry
For Cement Kiln Production

Previous quarry operator contract terminated. Quarry owner to take over operations.

Objectives
- Transition quarry from a “short-term-gain” viewpoint into a viable long-term operation
- Maximize recovery of 7 key limestone production horizons
- Meet limestone product blending requirements
- Potential to sell some waste rock as aggregate
- Relocate crusher facility to optimal long-term location

Cement Product Tonnage Requirements
- 1.7 Mtpy – 4.0 Mtpy limestone
Limestone for Cement Kiln Production - Study Scope

- Redevelop pit to access all working benches
- Optimize ramp designs for 5-year life
- Address all haulage access, ramp and storm water drainage in pit and dumps
- Develop 5-year production plan to meet limestone production requirements from 7 benches
  - Waste rock (or potential aggregate) from upper limestone and dolomite units
  - Cement from middle and lower limestone units
- Optimize waste rock removal
- Design waste dump capacity to accommodate waste rock
- Relocate in-pit crusher for optimal long-term operation

Limestone for Cement Kiln Production - Study Deliverables

- Annual detailed operations plans including:
  - Bench access ramps
  - Waste disposal placement
  - Crusher location
  - Pit water control designs
- Annual production sequence including:
  - Waste rock tonnage by horizon
  - Limestone product tonnage and quality by horizon
Developing Integrated Mine Plans

Benefits of a Robust Geological Model and Mine Plan

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