BUILDING A NEW ASSESSMENT TOOL FOR POTENTIAL RARE EARTH UNDERGROUND MINING PROJECTS

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Scope of Research

Special Evaluations in Rare Earth Mining

Traditional Evaluation Methods

REE-Mining Industry Specific Criteria

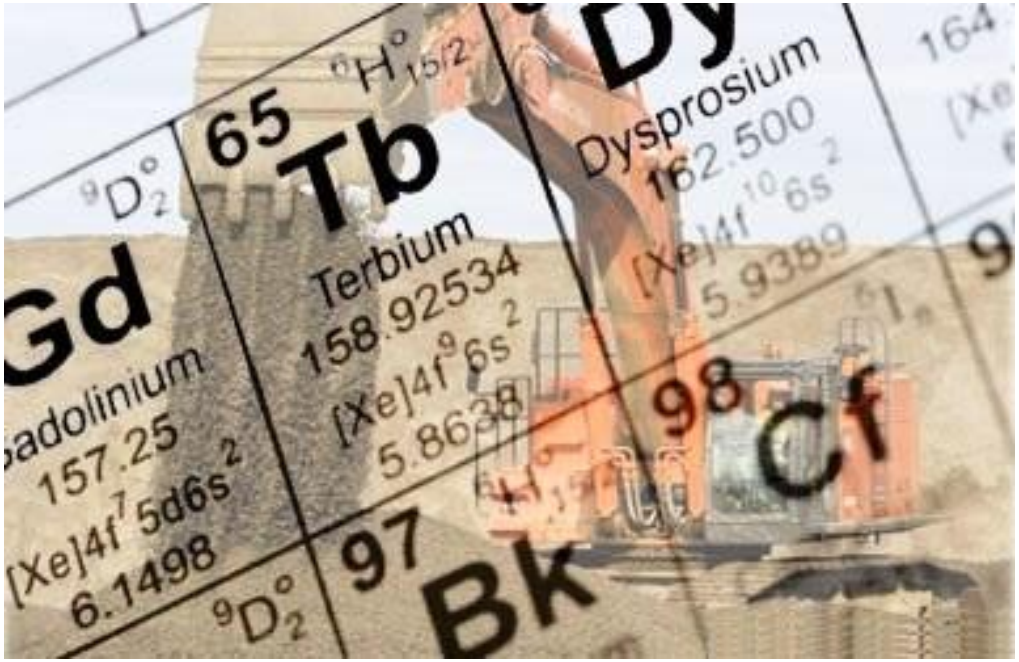
Numerical Methods & Techniques in the Assessment Tool

Structure of the Assessment Tool for

Rare Earth Underground Mining Projects

Special Evaluations in Rare Earth Mining

What makes rare earth mining so special

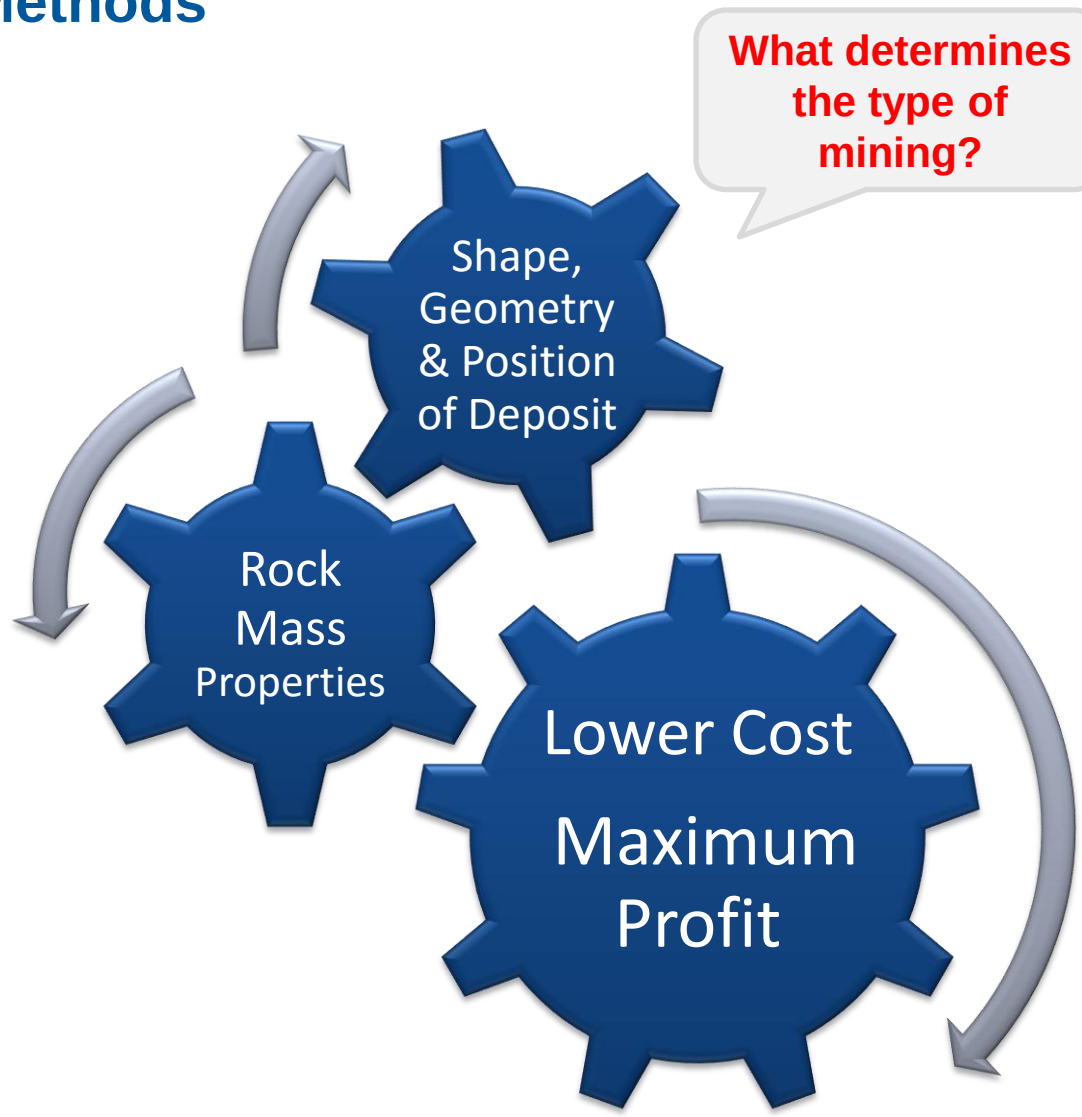


(Source: www.adn.com)

- Fragile market
- The Balance Problem
- Legislation
- Difficulties in processing
- Radioactivity
- Tailings
- Environmental issues
- Lack of proper knowledge & experience
- Social arguments

Traditional Evaluation Methods

- Boshkov & Wright (1973)
- Morrison (1976)
- Laubscher (1981)
- Nicholas (1981)
- Hartman (1987)
- UBC (1995)
- ...
- AHP
- ANP
- PROMETHEE
- Fuzzy logic techniques
- Trapezoidal fuzzy numbers



REE-Mining Industry Specific Criteria

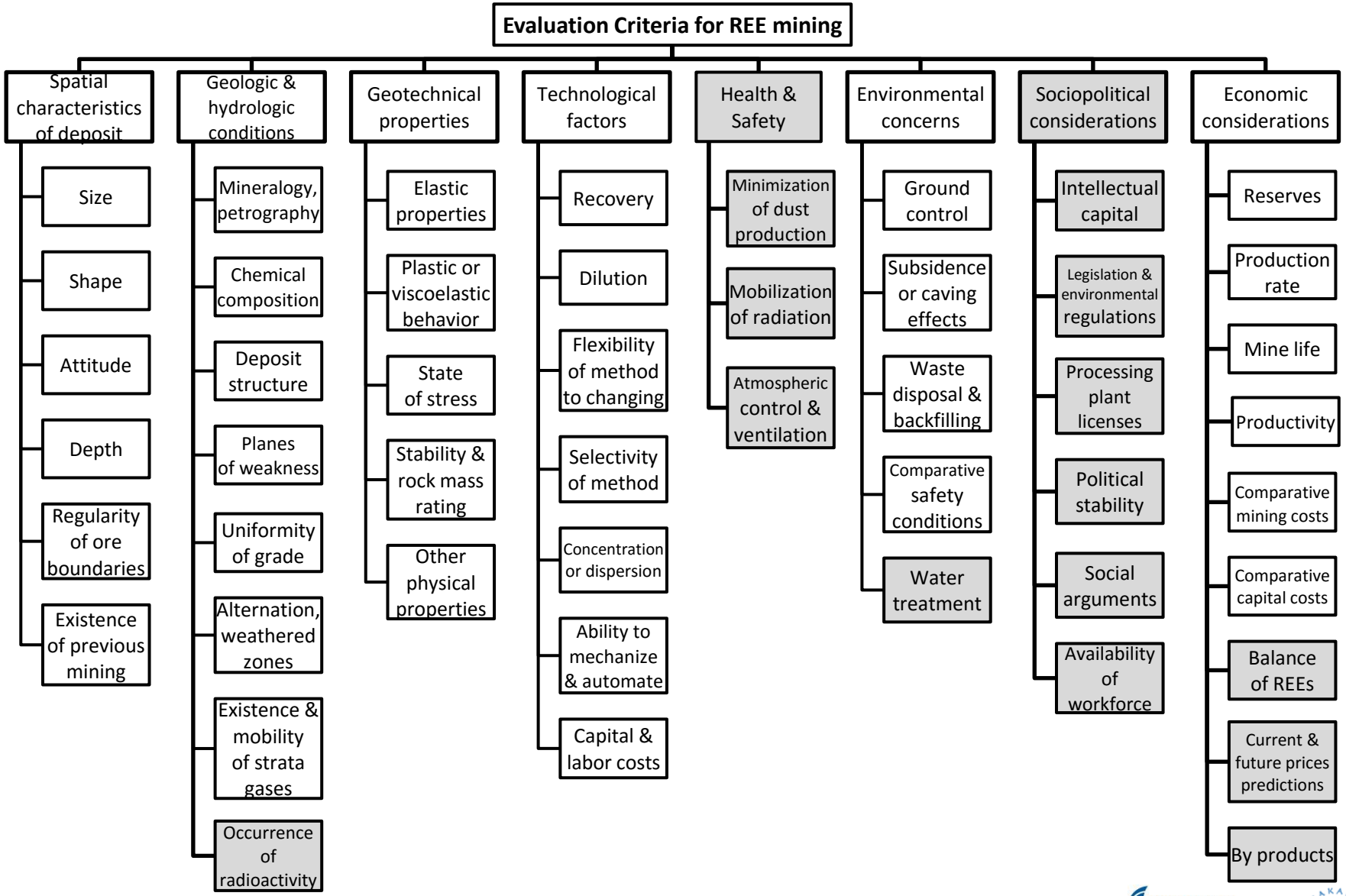
The triple-bottom-line (TBL)

The three pillars of sustainability

- Geological
- Technical
- …
- **Economic**
- **Environmental**
- **Sociopolitical**

Need for a detailed evaluation tool focused on the viability of REE projects

REE-Mining Industry Specific Criteria



(Source: Barakos & Mischo, 2015; modified after Hartman & Mutmansky, 2002)

Numerical Methods & Techniques in the Assessment Tool

- Analytical Hierarchical Process (AHP)
- Numerical approach for evaluation (Nicholas method)
- Sensitivity analysis model

The Analytical Hierarchical Process

- Multi-criteria decision process
- Subdivision of problems in an hierarchical form
- Pair-wise comparison of components
- Prioritization of criteria by setting weight factors on them

Relative Intensity	Definition	Explanation
1	Of equal value	Two elements are of equal value
3	Slightly more value	Experience slightly favors one element over another
5	Essential or strong value	Experience strongly favors one element over another
7	Very strong value	An element is strongly favored and its dominance is demonstrated in practice
9	Extreme value	The evidence favoring one over another is of the highest order of affirmation
2, 4, 6, 8	Intermediate values	When compromise is needed

The Analytical Hierarchical Process

Pair-wise comparison over *n* criteria

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix}, \quad a_{ii} = 1, \quad a_{ji} = 1/a_{ij}, \; a_{ij} \neq 0$$

Computing the vector of weights

$$\bar{a}_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \longrightarrow w_i = \frac{\sum_{i=1}^{n} \bar{a}_{ij}}{n}$$

Consistency of comparisons

$$CI = \frac{(\lambda_{\max} - n)}{(n-1)}$$

$$CR = \frac{CI}{RI}$$

Numerical Approach for Evaluation (Based on Nicholas)

- Ranking values for the suitability of a mining method to each criterion
- Intermediate values can be given for greater accuracy
- Many parameters are already quantified in classification schemes
- Evaluation of non-quantified criteria is based on experience and past cases

Ranking	Value
Strongly preferred	5
Slightly preferred	3-4
Probable	1-2
Unlikely	0
Eliminated	-49

(Source: modified after Nicholas, 1981)

Numerical Approach for Evaluation (Based on Nicholas)

Definition of deposit geometry and grade distribution

General shape/width	
Equi-dimensional	All dimensions are on same order of magnitude.
Platy–tabular	Two dimensions are many times the thickness, which does not usually exceed 100 m.
Irregular	Dimensions vary over short distances.
Ore thickness	
Narrow	<10 m
Intermediate	10–30 m
Thick	30–100 m
Very thick	>100 m
Plunge	
Flat	<20°
Intermediate	20°–55°
Steep	>55°
Depth below surface	Provide actual depth.
Grade distribution	
Uniform	Grade at any point in deposit does not vary significantly from mean grade for that deposit.
Gradational	Grade values have zonal characteristics, and the grades change gradually from one to another.
Erratic	Grade values change radically over short distances and do not exhibit any discernible pattern in their changes.

(Source: Nicholas, 1981)

Rock mechanics characteristics

Rock Substance Strength (uniaxial strength/overburden pressure)		
Weak	<8	
Moderate	8–15	
Strong	>15	
Fracture Frequency	**No. of Fractures/m**	**% RQD**
Very close	>16	0–20
Close	10–16	20–40
Wide	3–10	40–70
Very wide	<3	70–100
Fracture Shear Strength		
Weak	Clean joint with smooth surface or fill with material with strength less than rock substance strength	
Moderate	Clean joint with rough surface	
Strong	Joint filled with material that is equal to or stronger than rock substance strength	

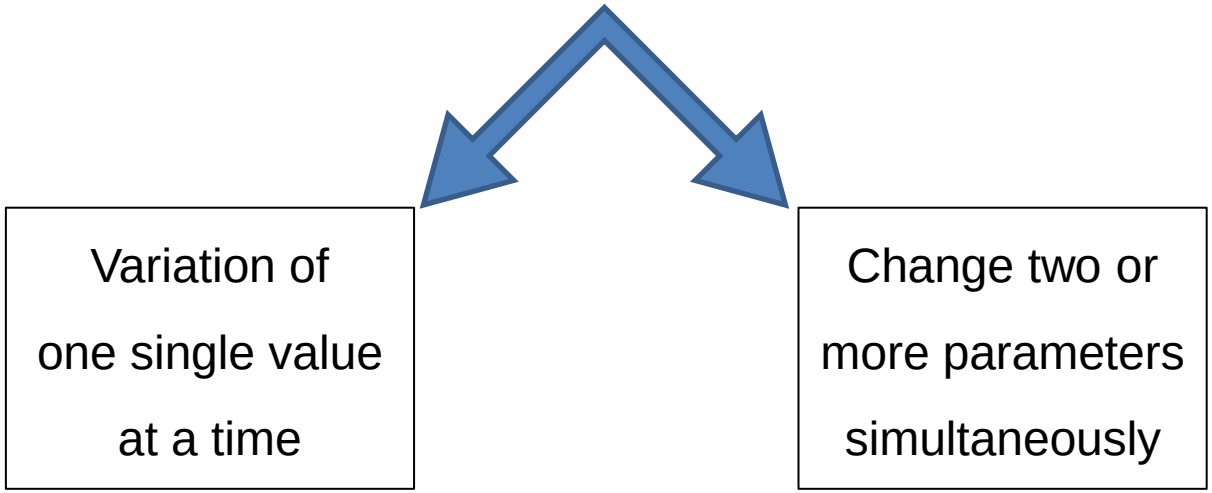
(Source: Nicholas, 1992)

The Sensitivity Analysis Model

- “Subjective” decisions in the selection process
- Most critical criteria have the highest weight factors (**?**)

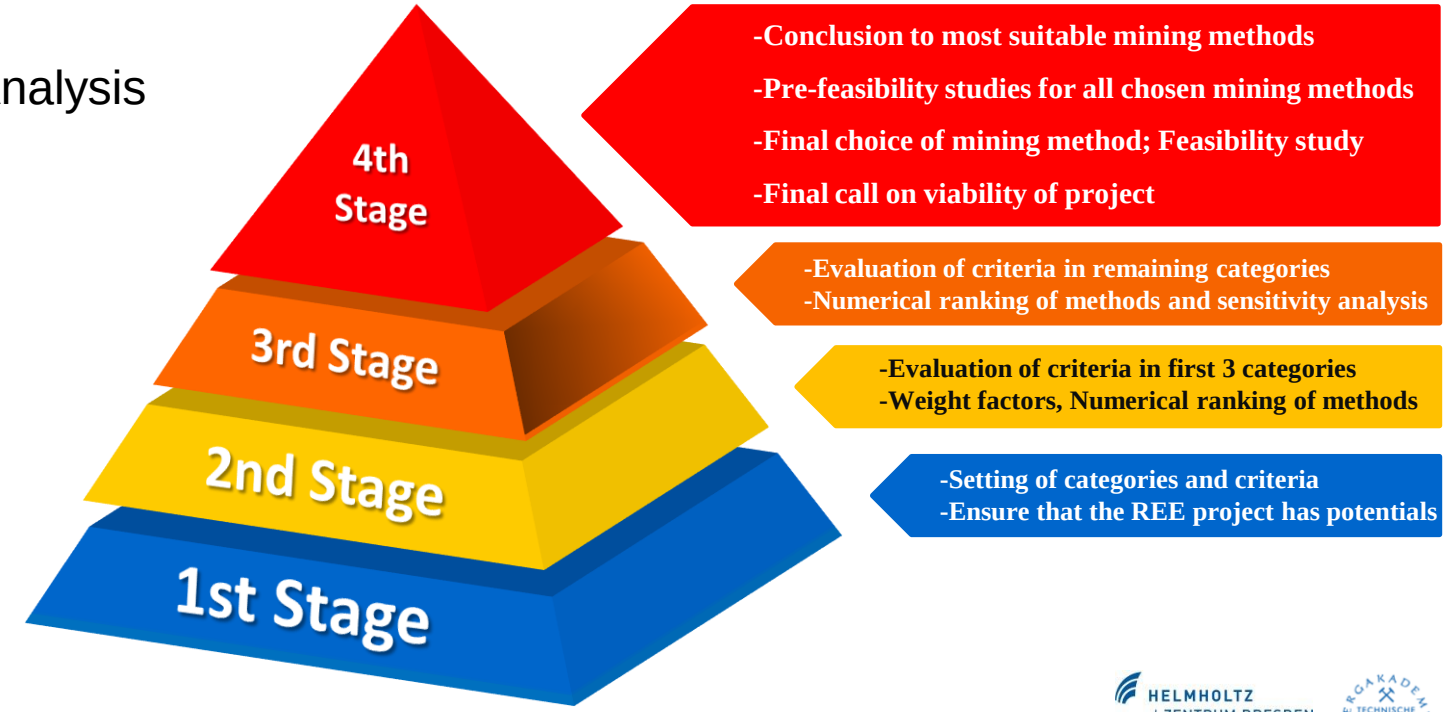
Sensitivity Analysis Model on Weights

- Smallest change on weights that can influence the ranking of mining methods



Structure of the Assessment Tool

- Quantification and assessment of all possible factors
- Critical ability using quantified data and experience
- AHP and weight factors
- Re-evaluation loops
- Sensitivity Analysis



Classification of Mining Methods

Locale	Class	Method
Surface	Mechanical	Open pit mining Quarrying Open cast (strip) mining Auger mining
	Aqueous	Hydraulicking Dredging Borehole mining Leaching
Underground	Unsupported	Room-and-pillar mining Stope-and-pillar mining Shrinkage stoping Sublevel stoping
	Supported	Cut-and-fill stoping Stull stoping Square-set stoping
	Caving	Longwall mining Sublevel caving Block caving

(Source: modified after Hartman & Mutmansky, 2002)

Structure of the Assessment Tool

1st Evaluation Stage

1st Stage

Start of evaluation

-Set the categories and criteria

Evaluation of some basic criteria:

-Geographic conditions (location, social)
-Infrastructure
-Mineralogy, grade, REE-type
-Metallurgical tests, recovery
-Legislation, licenses

↓

Ensure that the REE project has potentials

2nd Stage
Early evaluation stage of criteria
-In this stage we examine the criteria in the first 3 categories

i) spatial characteristics of deposit
ii) geologic-hydrologic conditions
iii) geotechnical properties

-AHP for weighted criteria
-Ranking of mining methods
-Surface/underground mining
-Elimination of unsuitable mining methods to reduce
-Scores of qualifying methods are transferred to next stage

3rd Stage
Main evaluation stage of criteria

-In this stage we examine the criteria in the categories 4-8

iv) Economic considerations
v) Technological factors
vi) Environmental concerns
vii) Sociopolitical considerations
viii) Health & safety concerns

-AHP for weighted criteria

-Ranking of mining methods

-sensitivity analysis for criteria

4th Stage
Conclude to 2-3 most suitable methods;
-Prefeasibility studies, -environmental studies } for all of them

Final decision on the method

-Feasibility study
-Decision on investment → Yes / No

NEPA and permitting

Financing

END OF EVALUATION
START OF PROJECT

Structure of the Assessment Tool
2nd Evaluation Stage

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Conclusions and Perspectives

- An approach to create an integrated evaluation process
- The tool is applicable to other kind of deposits

- Weight factors calculated with Analytical Hierarchical Process
- Ranking of mining methods with the “Nicholas” ranking system

- No active REE underground mines to derive data, knowledge, experience
- Next step is to investigate interesting REE potential projects

- The goal is to check the functionality and consistence of the tool
- Optimization of evaluation process
- Combination of the theoretical tool with mine planning design software

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THANK YOU FOR YOUR ATTENTION

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