Innovative Technologies for the Extraction of Ni, Co & Mn From Laterite Crusts

PRESENTED BY:

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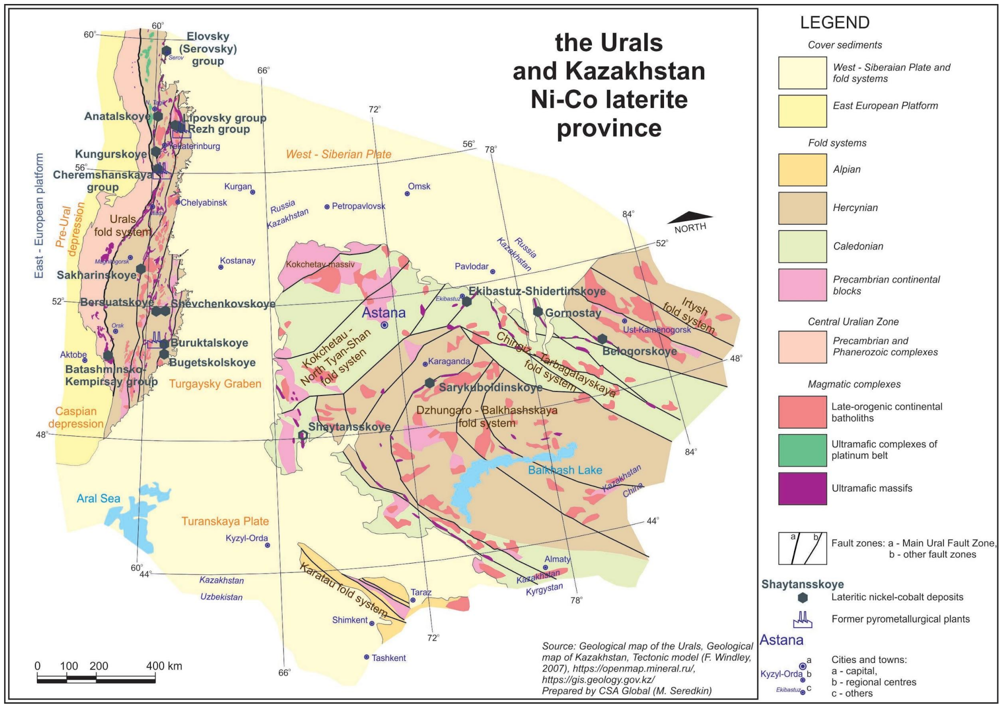
Sustainability is our business

Agenda

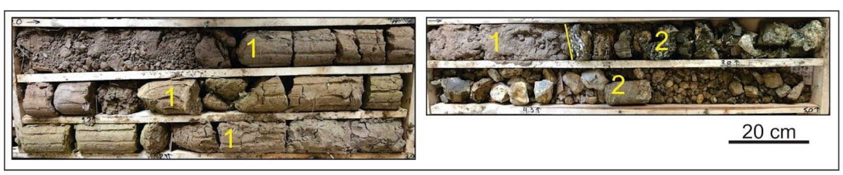
1. Why innovative technologies in the Ural-Kazakhstan province
2. Past pyrometallurgical operations
3. Overview of Ni-Co extraction technologies
4. Heap Leaching & In-Situ Recovery
5. Development the innovative technologies
6. Improvements of the innovative technologies
7. Applicability of new technologies for other regions

Why innovative technologies in the Ural-Kazakhstan province

- Innovative technologies were developed in the Ural – Kazakhstan Ni-Co laterite province due to two factors:
- In the past deposits in this province were subject to pyrometallurgical operations which are now uneconomic.
- The Ural-Kazakhstan province hosts Mesozoic Ni-Co mainly nontronite deposits with low average grade 0.3–1.3% Ni, 300–500 ppm Co.

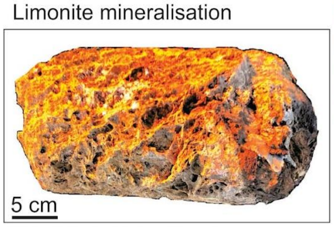


Mineralisation in the Ural-Kazakhstan Ni-Co laterite province



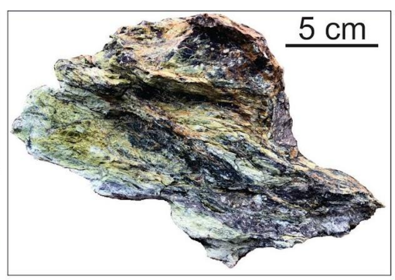
Cover / Overburden sediments (1) and Redeposited weathering crust (2)

Limonite mineralisation

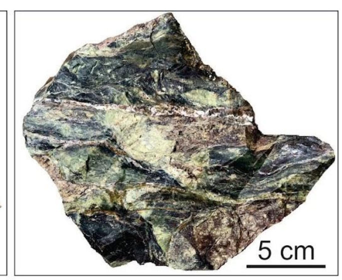


"Birbirite"- high silica lenses

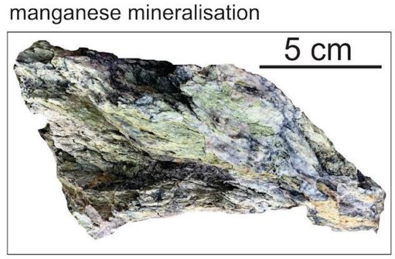
Relict of nontronite in limonite zone



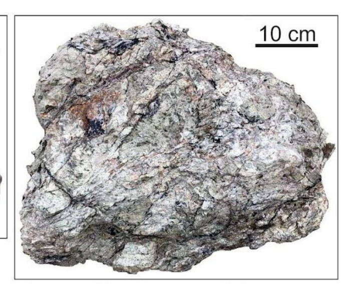
Nontronite with lens of manganese mineralisation



Nontronite with silicification

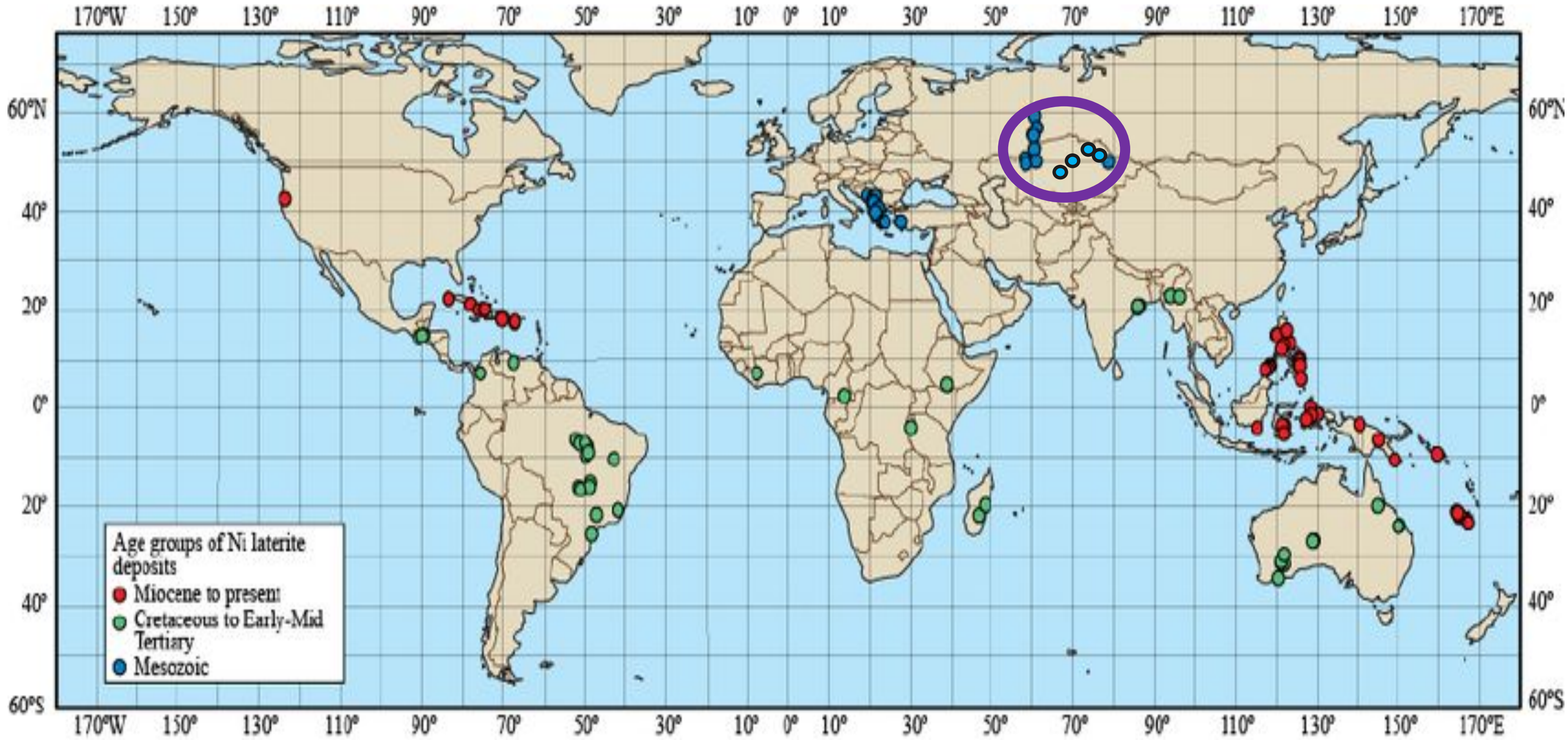


Silicified nontronite (green opal)

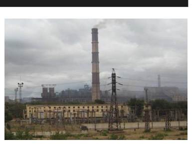
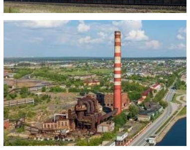


Nontronitised serpentinite

Location of the Ural-Kazakhstan Ni-Co laterite province



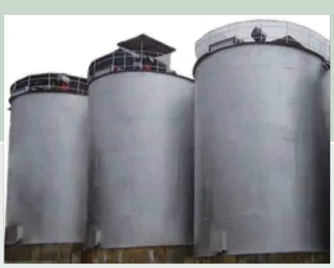
Past pyrometallurgical operations

<table>
<tr><th></th><th>2002</th><th>2003</th><th>2004</th><th>2005</th><th>2006</th><th>2007</th><th>2008</th><th>2009</th><th>2010</th><th>2011</th><th>2012</th><th>2013</th><th>2014</th><th>2015</th><th>2016</th><th>2017</th><th>2018</th><th>2019</th><th>2020</th><th>2021</th><th>2022</th><th>2023</th><th>2024</th></tr>
<tr><td>New technologies</td><td colspan="10">Initial development</td><td colspan="4"></td><td colspan="9">Application in test regime</td></tr>
<tr><td></td><td colspan="11">YouzhUralNickel Operation Plant</td><td colspan="12">YouzhUralNickel Idle Plant</td></tr>
<tr><td></td><td colspan="15">UfaleyNickel Operation Plant</td><td colspan="4">UfaleyNickel Idle Plant</td><td colspan="4">UfaleyNickel Demolished Plant</td></tr>
<tr><td></td><td colspan="15">RezhNickel Operation Plant</td><td colspan="8">RezhNickel Idle Plant</td></tr>
</table>

Energy intensive technologies with high emissions

Class of the process		Type of the process	Products
	Pyrometallurgy	Smelting of Saprolite ore	Ferronickel production
	Pyrometallurgy	Smelting of Limonite ore	Nickel pig iron
	Combination of Pyrometallurgy and Hydrometallurgy	Caron process for Limonite ore: Reduction at high temperature Ammonium leaching, SX processing of pregnant solutions	SX with following precipitation Ni and Co products

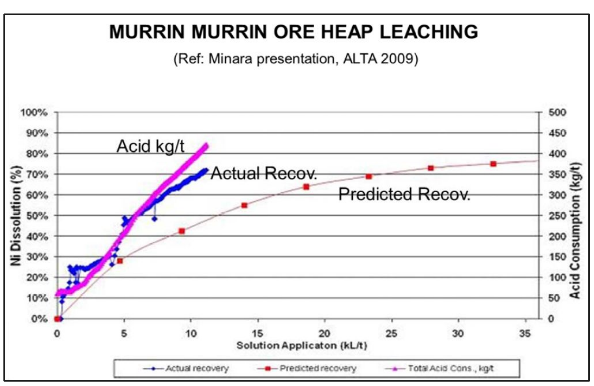
Conventional CAPEX and OPEX intensive technologies

Class of the process		Type of the process	Products
	Hydrometallurgy - HPAL	For low-magnesium ore Processing of pregnant solutions by sulfidisation and SX	Ni and Co products (MHP, sulphates etc)
	Hydrometallurgy - HPAL	For low-magnesium ore Processing of pregnant solutions by IX and SX – CleanTeQ process	Ni, Co, Sc products (MHP, sulphates etc)
	Hydrometallurgy – AL (tank leaching)	Leaching by Sulphuric acid Limonite and saprolite ore	Ni and Co products (MHP, sulphates etc)
	Hydrometallurgy – AL (tank leaching)	Leaching by Hydrochloric acid Saprolite ore	Ni and Co products (MHP, sulphates etc)

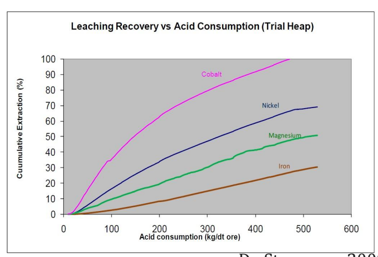
Innovative technologies

Class of the process		Type of the process	Products
	Hydrometallurgy – AL (tank leaching)	Leaching by Sulphurous acid Co-Mn limonite ore	Co and Mn products (MHP, sulphates etc)
	Hydrometallurgy – AL (tank leaching)	Leaching by Nitric acid (DNi process) Limonite and saprolite ore	Ni, Co, Sc, Mg products (hydroxides / oxides)
	Hydrometallurgy – Heap leaching	Leaching by Sulphuric acid Limonite and saprolite ore	Ni and Co products (MHP, sulphates etc)
	Hydrometallurgy – Heap leaching	Leaching by Sulphurous acid Limonite and saprolite ore	Ni and Co products (MHP, sulphates etc)
	Hydrometallurgy – In-Situ Recovery	Leaching by Sulphuric acid Limonite and saprolite ore	Ni and Co products (MHP, sulphates etc)
	Hydrometallurgy – In-Situ Recovery	Leaching by Sulphurous acid Limonite and saprolite ore	Ni and Co products (MHP, sulphates etc)

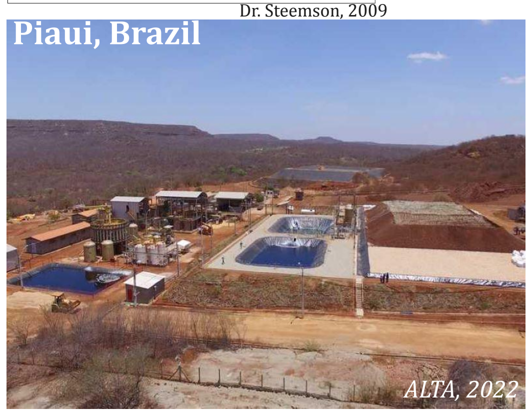
Heap leaching for Nickel-Cobalt



ALTA, 2009



Dr. Steemson, 2009

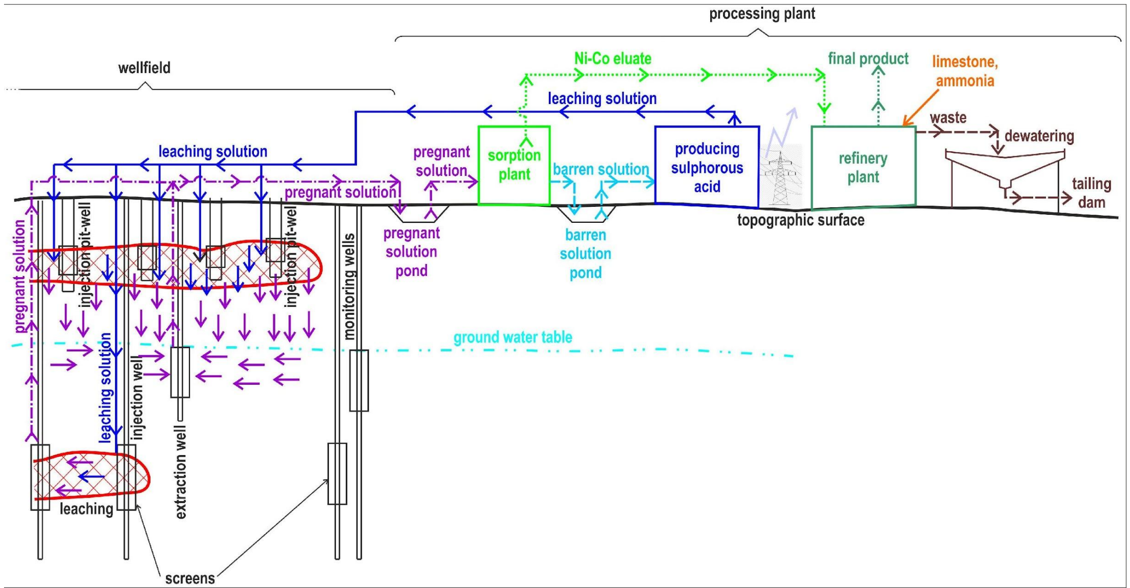


In 2016-2017, Brazilian Nickel successfully demonstrated large-scale heap leaching, purification and recovery of Ni and Co from Piaui ore.

The company started commercial operation in 2022, expecting full-scale operation could produce an average of 25,000 tpa of Ni and 900 tpa of Co

In-Situ Recovery for Nickel-Cobalt

- In situ recovery (ISR) is one of the most effective methods to address mining costs.
- The key feature of ISR is transferring a significant proportion of the hydrometallurgical processing of mineralised bodies to the subsurface, to directly obtain solutions of metals.



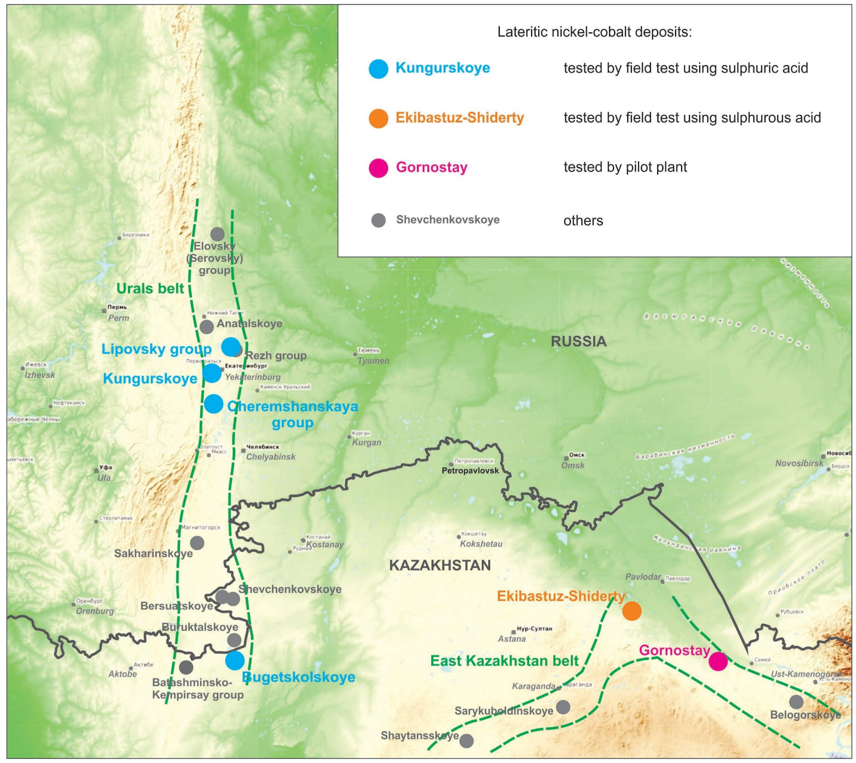
In the Urals-Kazakhstan Province ISR was considered the most effective innovative method for Ni-Co extraction

History of Nickel-Cobalt ISR development

- **2002-2008**: Start of research, laboratory tests. (UGTC)
- **2008-2009**: Field ISR tests for Ni-Co ISR by sulphuric acid. (UGTC)
- **2009-2011**: Selection of sulphurous acid as leaching solutions for Ni-Co ISR. (UGTC)
- **2016-2017**: Column tests by sulphurous acid. (UGTC/ATS)
- **2017-2018**: Field ISR for Ni-Co ISR by sulphurous acid. (UGTC/ATS)
- **2018**: FS with processing of pregnant solutions after HPAL by IX. (CleanTeQ)
- **2019**: The First Scoping Study for Ni-Co ISR. (CSA Global – now ERM)
- **2019-2021**: Pilot Plant for Ni-Co ISR. (Kaznickel/ MTC)
- **2022 – 2024**: Improving and Simplifying Technology for ISR and heap leaching. (ERM, MTC)

History of Nickel-Cobalt ISR development

- ISR was tested widely in the Ural-Kazakhstan Ni-Co laterite province
- ISR by Sulphuric acid was tested in the initial period on the Urals Ni-Co deposits
- ISR by Sulfurous acid was tested and is currently developing on the Kazakhstan Ni-Co deposits



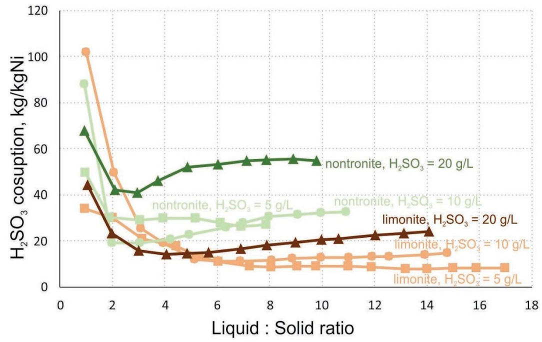
Initial period of R&D of Ni-Co ISR technology

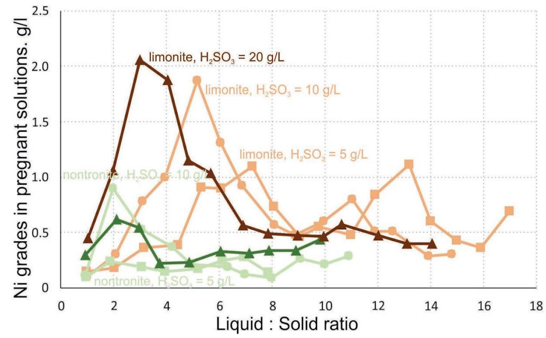
The most complete field test was performed on the Rogozhnsky deposit (South Ural) (personal communications).

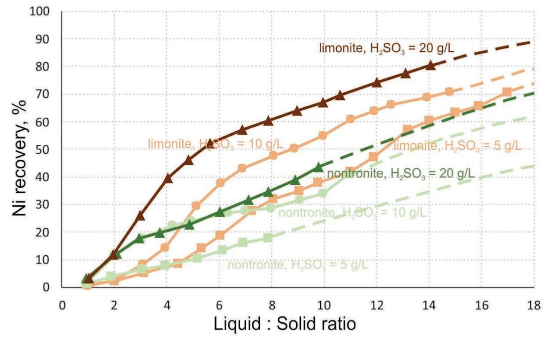
- Period: 2008-2009
- Tonnage: 410 t @ 0.61%Ni @ 2.5 t Ni
- Duration: 8 months
- Leaching Solution (Lixiviant): Sulphuric Acid
- Nickel recovery 8% (1% in month)
- Nickel grade in pregnant solutions up to 750 mg/L (average in the best month 500 mg/L)
- Acid consumption – 20 t (~50 kg/t or ~400 kg/t for target nickel recovery 65%
- L/S: 2.1 m^3/t or ~17 m^3/t for target nickel recovery 65%.

Investigation of leaching using sulphurous acid

- Successful investigations of sulphurous acid as a lixiviant for leaching Ni-Co laterite mineralisation – limonite and silicate
- Column tests for investigations of leaching dynamics, components recovery and acid consumption



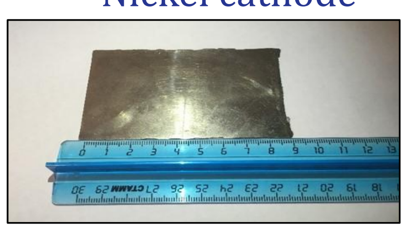




Field test at the Ekibastuz-Shiderty deposit in 2017-2018

Test results demonstrate a principal opportunity to produce a final product of nickel and cobalt cathode from pregnant solutions after ISR by IX processing and, following neutralisation, SX and electrowinning processes

Nickel cathode



Cobalt cathode

The first Scoping Study for Ni-Co ISR Hydrogeology

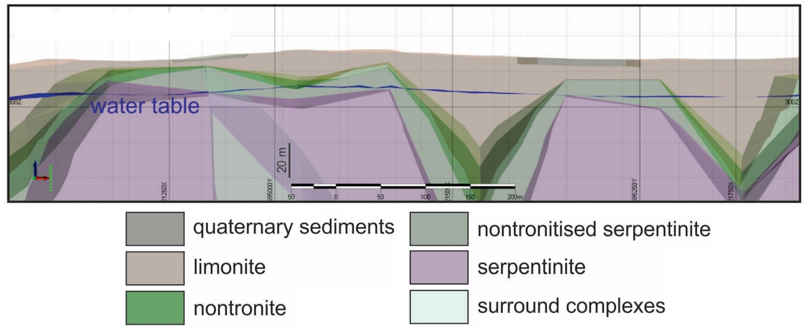
The average measured permeability by classical hydrogeological tests is:

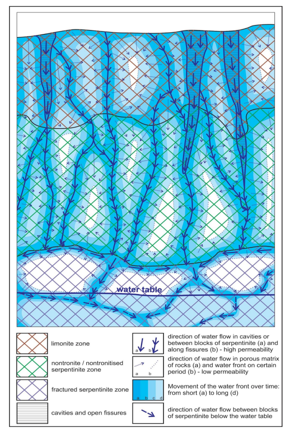
- 0.1-0.3m/day

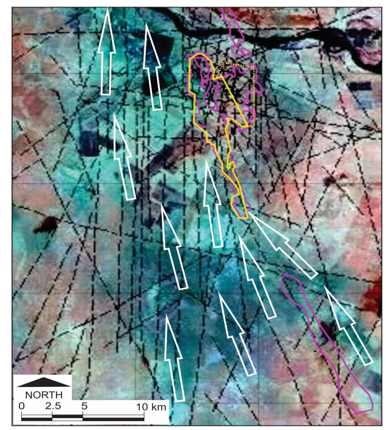
And in fractured zones up to 5m/day

However, permeability after acidification is probably higher and average pumping rate is 1.6 m^3/hour

Groundwater table is located in fractured serpentinites usually

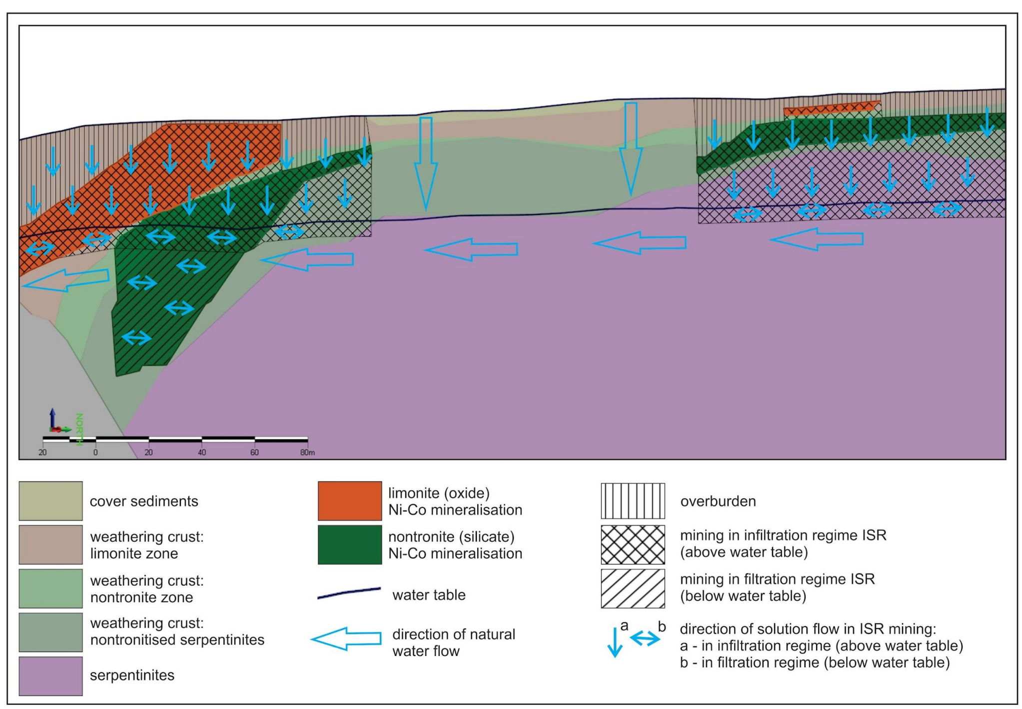






The first Scoping Study for Ni-Co ISR Mining Scheme

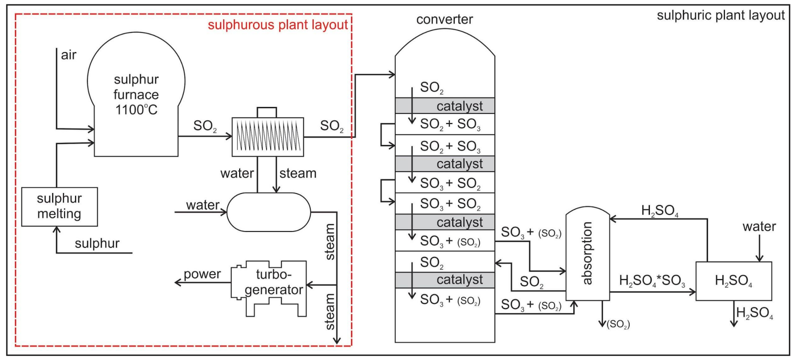
- Operational cells above the water table (infiltration ISR) emulate heap leaching with vertical movements of leaching solutions and collection of pregnant solutions at the water table.
- Operation cells below the water table (filtration ISR) are classical style of ISR, with sub-horizontal movement of pregnant solutions.



The first Scoping Study for Ni-Co ISR Lixiviant

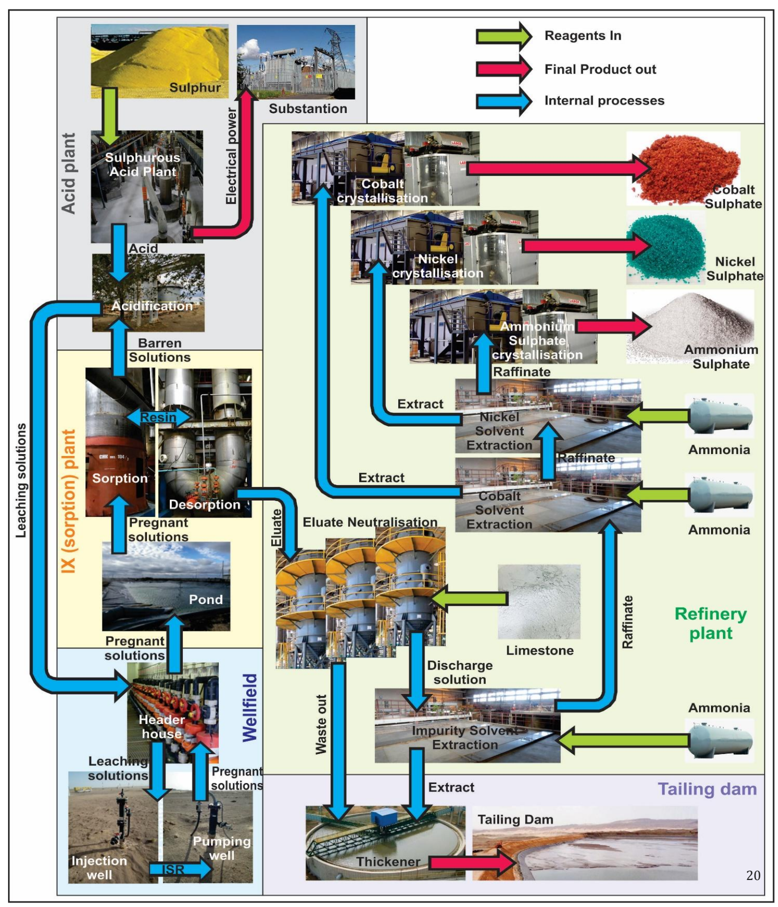
Sulphurous acid preparation is part of the Sulfuric acid plant and may be implemented on site easily for preparation lixiviant from lump sulphur

A sulphurous acid plant was designed for the Mt Thirsty cobalt project in Western Australia

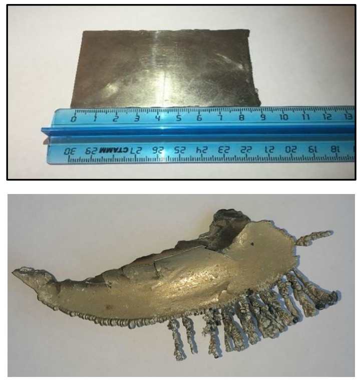


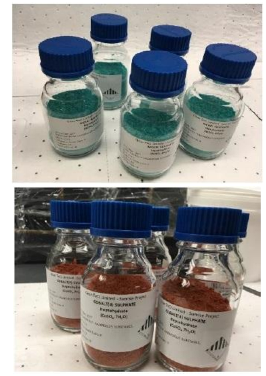
The first Scoping Study for Ni-Co ISR Processing of solutions

- ERM Sustainable Mining Services (formerly CSA Global) prepared the first Scoping Study for Ni-Co ISR based on UGTC tests, the CleanTeQ flowsheet.
- Processing of pregnant solutions by Ion Exchange (sorption to resin) and following processing of eluate – neutralisation, solvent extraction and crystallisation of the final product.
- Power and steam will be produced in a Sulphurous acid plant, and the project will have **almost zero carbon dioxide emissions** due to the generation of steam and electrical power.



The first Scoping Study for Ni-Co ISR
Final products





Option 1 – production Mixed Hydroxide Precipitate (MHP)

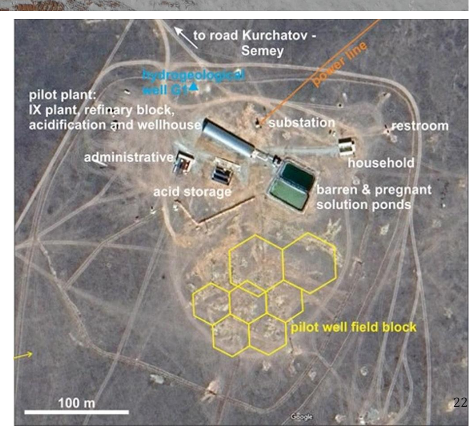
Option 2 – production Cathode Ni and Co

Option 3 – production sulphate of Ni and Co

Pilot operation of the Gornostay deposit

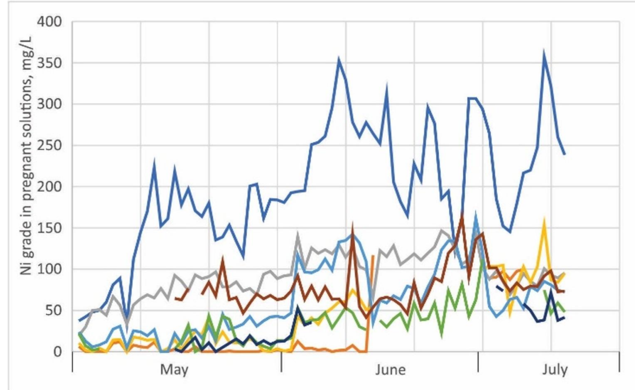
Kaznickel team constructed a Pilot Block and Plant at the Gornostay project in 2018:

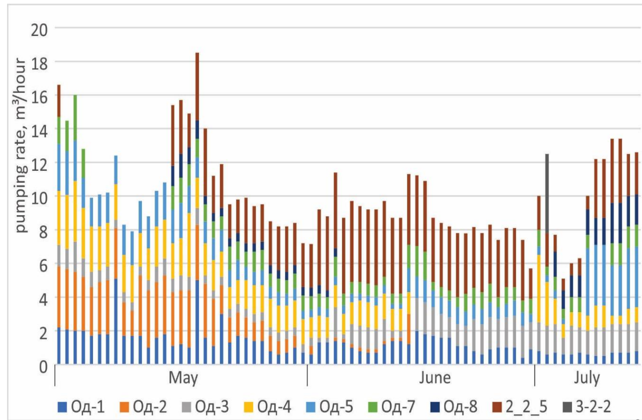
- Wellfield
- Acidification block
- IX block
- Neutralisation
- Precipitation MHP



Pilot operation of the Gornostay deposit

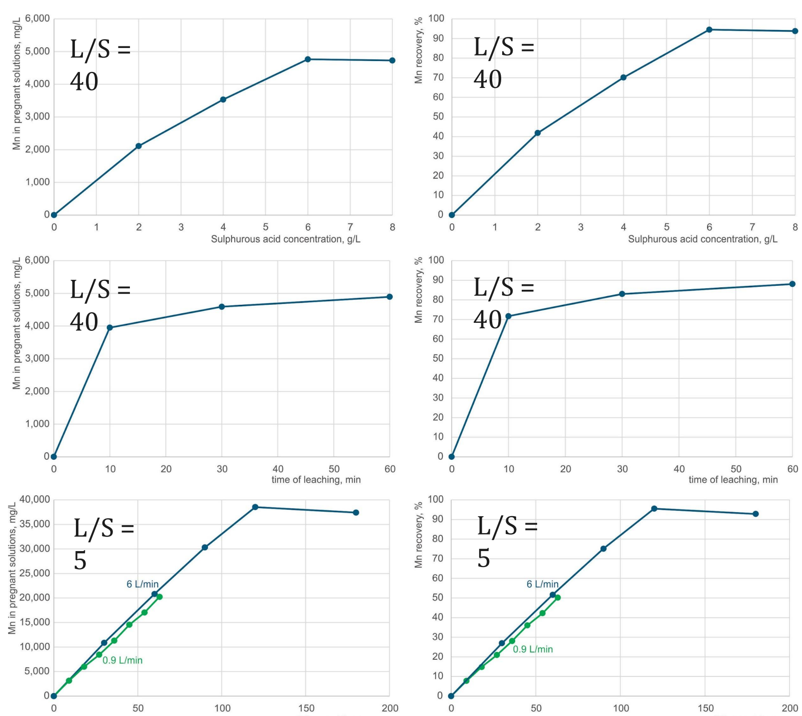
- Kaznickel uses mixed sulphurous and sulphuric acid for nickel leaching.
- The average pumping rate of pumping wells is 1.6 m^3/hour.
- Kaznickel has achieved the stable work of ISR operation block
- Nickel grade in pregnant solutions reached up to 350 mg/L, with an average of 150-200 mg/L, comparable to estimated parameters in the Scoping Study.





Manganese leaching by Sulphurous acid

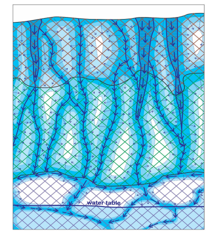
- Manganese mineralisation with a low average MnO grade (17%) was tested for leaching by sulphurous acid
- Manganese recovery by sulphurous acid reaches >90% whereas by sulfuric acid is less than 20%
- The best results were for SO_2 gas as lixiviant with Mn grade in pregnant solutions up to 40 g/L
- Manganese was extracted from pregnant solutions in MnO_2 form by electrowinning



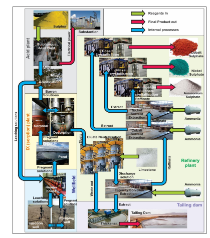
Challenges of developed technologies

- Very low permeability of material with high clay content in heap leaching

- ISR above water is poorly managed and sweep factor can be very high up to 50% as demonstrated the San-Manuel copper project



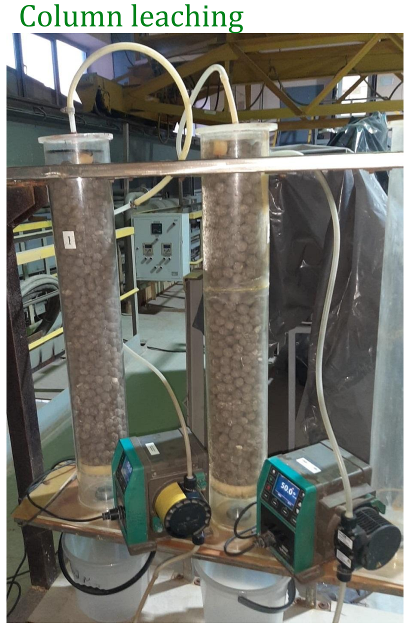
- Very complicated the CleanTeQ flowsheet is for poor pregnant solutions, may require two stages of sorption for production eluate with an acceptable grade of nickel



Tests for the potential improvements

Initial agglomerates

Column leaching

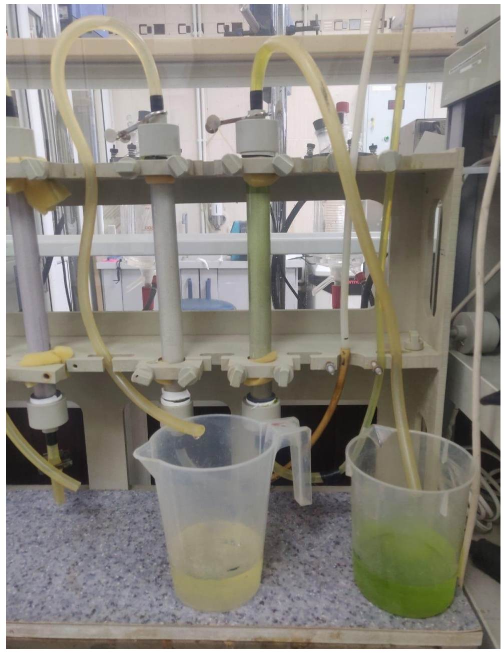


Agglomerates after leaching

- Polymeric agglomerate was found to be stable in acid heap leaching

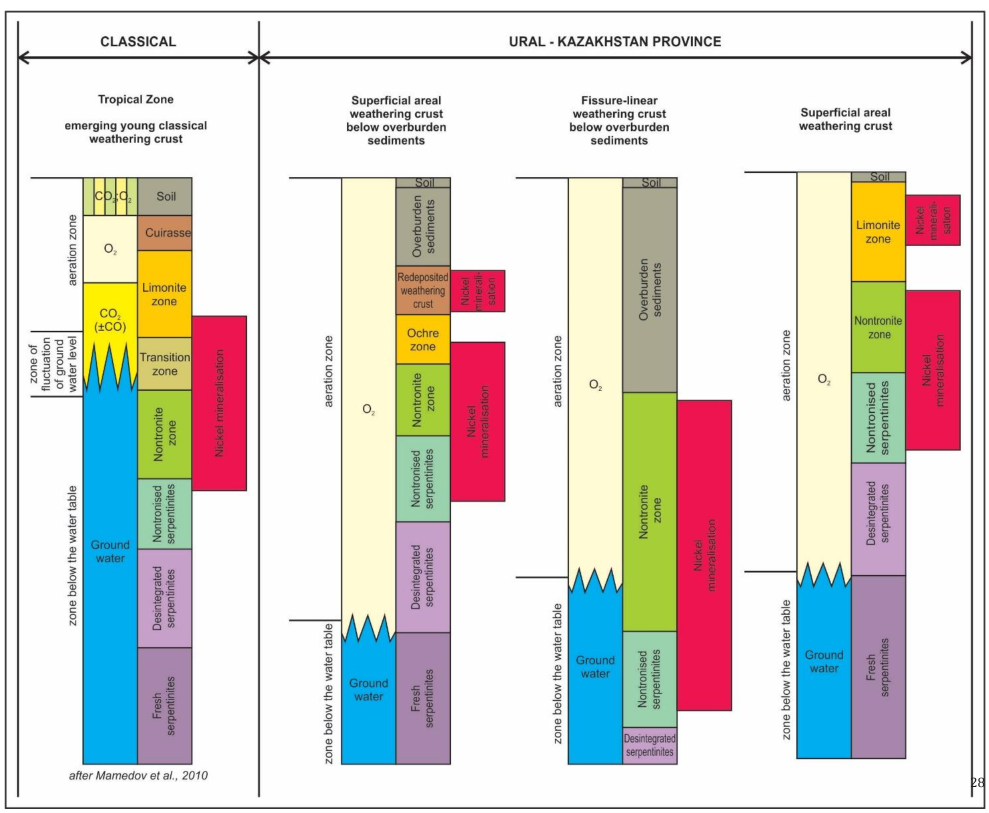
Tests for the potential improvements

- Selective sorption of Ni on Lewatit TP-220 resin, followed by removal of iron from the resin using ‘soft’ acid solutions
- Desorption of Ni by 7-10% ammonium hydroxide, producing an eluate of Ni ammine complexes such as $Ni(NH_3)_4(OH)_2$, $Ni(NH_3)_6(OH)_2$ etc.
- Ammine complexes are easily dissociated to produce $Ni(OH)_2$, with ammonia recycled to the IX process



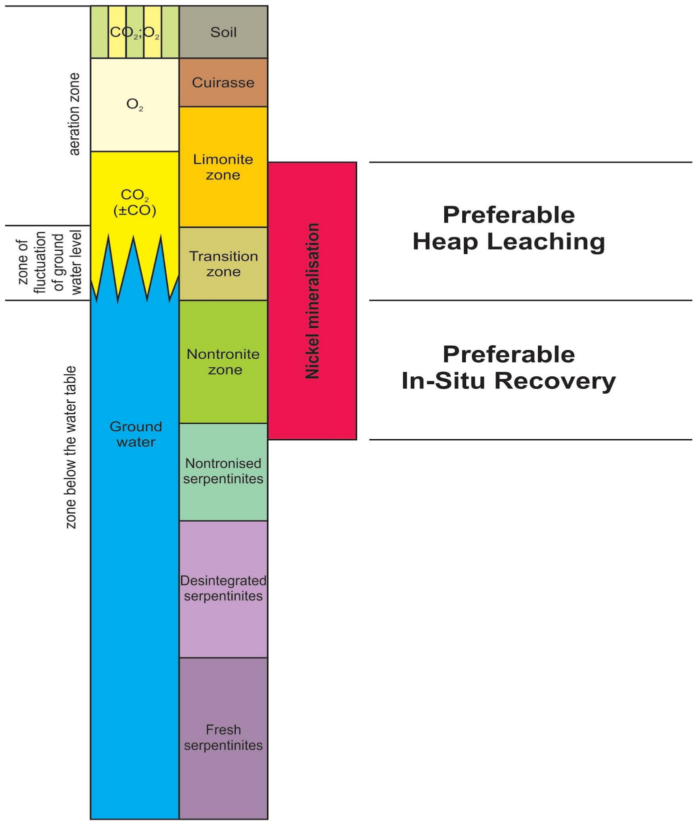
Distribution of technologies to other regions

- Ni-Co laterite deposits in the Urals-Kazakhstan province are poor and geology complicated, and technologies are still developing to be economic
- However, all found solutions are applicable to Ni-Co laterite deposits in other regions with classical zonation and higher Ni-Co grades



Application of this approach to other regions

- Mineralisation above the water table can be extracted by heap leaching and below the water table by ISR
- Sulphurous acid is recommended as the preferred lixiviant



Based on materials from: Mamedov et al., 2010

Thank you

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