Underground Construction and Mining

Terrestrial and Lunar Applications

LSIC Excavation and Construction Brief
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MoonRise Inc.

PENGUIN ASI
Penguin Automated Systems Inc.

moonrise

Dr. Greg Baiden

- A senior executive for Inco Limited one of the largest mining, processing and metal finishing complex/company in the world. This company had a worldwide reach producing 500 million pounds of nickel, 500 million pounds of copper and 38 other metals and chemicals per year. These products were distributed around the world. At one time this ore body produced 95% of the worlds nickel (today about 20%) from what is thought to be an ancient asteroid hit (1986-2001)
- Global head of R&D for Inco Limited leading and developing the next generation mining technology through corporate R&D of approximately $500 million during my tenure (1986-2001) including leading exploration and delineation approximately 750,000 feet per year of drilling to explore and map the Sudbury ore body
- Leading a global initiative called the "Mining Automation Program" MAP (1993 – 2001) a Canadian, European, USA initiative to build the robotic mine of the future and operationally responsible for mine operation
- Ph.D. Work (1993) in creating and field testing a new high bandwidth underground communication system to interface fleets (100's) of mobile robots that perform mining tasks of drilling, blasting, transport and processing of material
- Leading my entrepreneurial businesses: Penguin Automated Systems Inc. (2001-present), Moonrise Inc. (2018 to present) and current work in agricultural robotics, Mobile CNC machine development and GPS denied 3-D mapping and "bigdata"
- Leading Shackleton Energy mining plans for the moon
- Leading in the development of the Longnow Clock chamber design and construction
- Canadian Research Chair in Mine Robotics and Automation and/or my current move to the University of Memphis to lead an Agricultural Robotics Institute.
- Lead author of the Canadian Space Agency strategic plan for Mining the Moon (co-author Brad Blair)

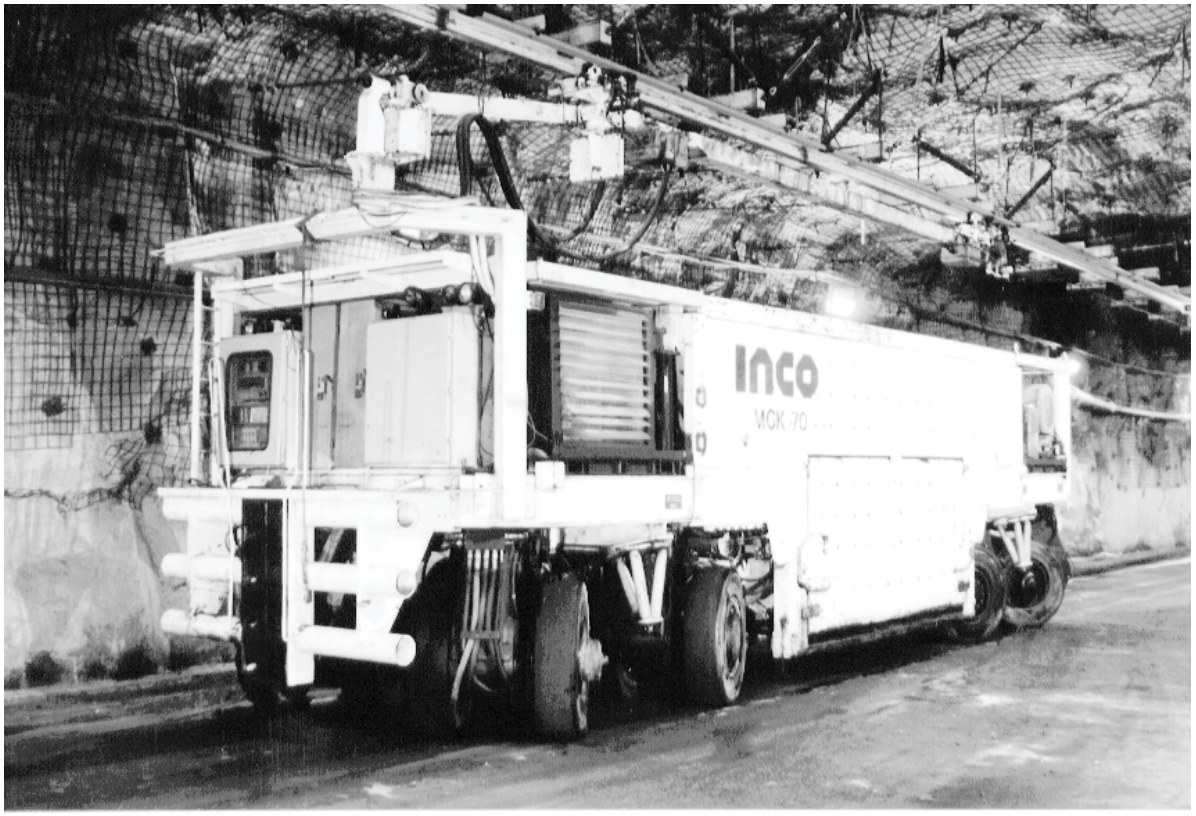
Penguin Automated Systems Inc.

- Basic ways we work: Strategic Planning; Creating Telerobotic Systems for strategic and emergency situations to preserve life; Productizing solutions with markets.
- Private R&D company working to solve problems that eliminate risk to personnel charged with solving the issue.
- Our Team - Interdisciplinary group of scientists, engineers and craft people to build and/retrofit machine systems
- Our Facility – 50,000 square foot with mechanical, electrical, electronic and systems tools for intelligent and robot systems prototyping, manufacture and commercialization
- Intellectual Property – Penguin holds patents and significant know-how in mining and other robotics and technology
- Formed MoonRise Inc. a US based organization to work on off-world mining

Penguin ASI's work is shifting the mining industry to human-less operations

- I have led that change for some of the largest mining organizations in the world
- The terrestrial "human-less" mine is a constant journey to move personnel further and further from the working face

The move to automated/“human-less” mining started in Canada with the first driverless 70 ton truck in 1988



Automatic Truck led to:

- 1988-1993 Baiden Thesis “A study in underground mine automation”
  - Computer networking developed for mobile robot operation
- Demonstration of LHD operation from a surface control room (1992)
  - CIM demonstration 1 operator runs 2 LHDs for Toronto in Copper Cliff
- Mining Automation Project (MAP) was conceived 1993-1994 by Baiden and run from 1995 to 2000

Longhole Production Drill Automation

1 person/3 drills – drilling 30,000 feet per month

+ visited by JPL to justify drilling mission to Mars

- remained in operation until 2018 for 25 years over the broadband network systems developed by Baiden Ph.D. work

Mining Automation Program

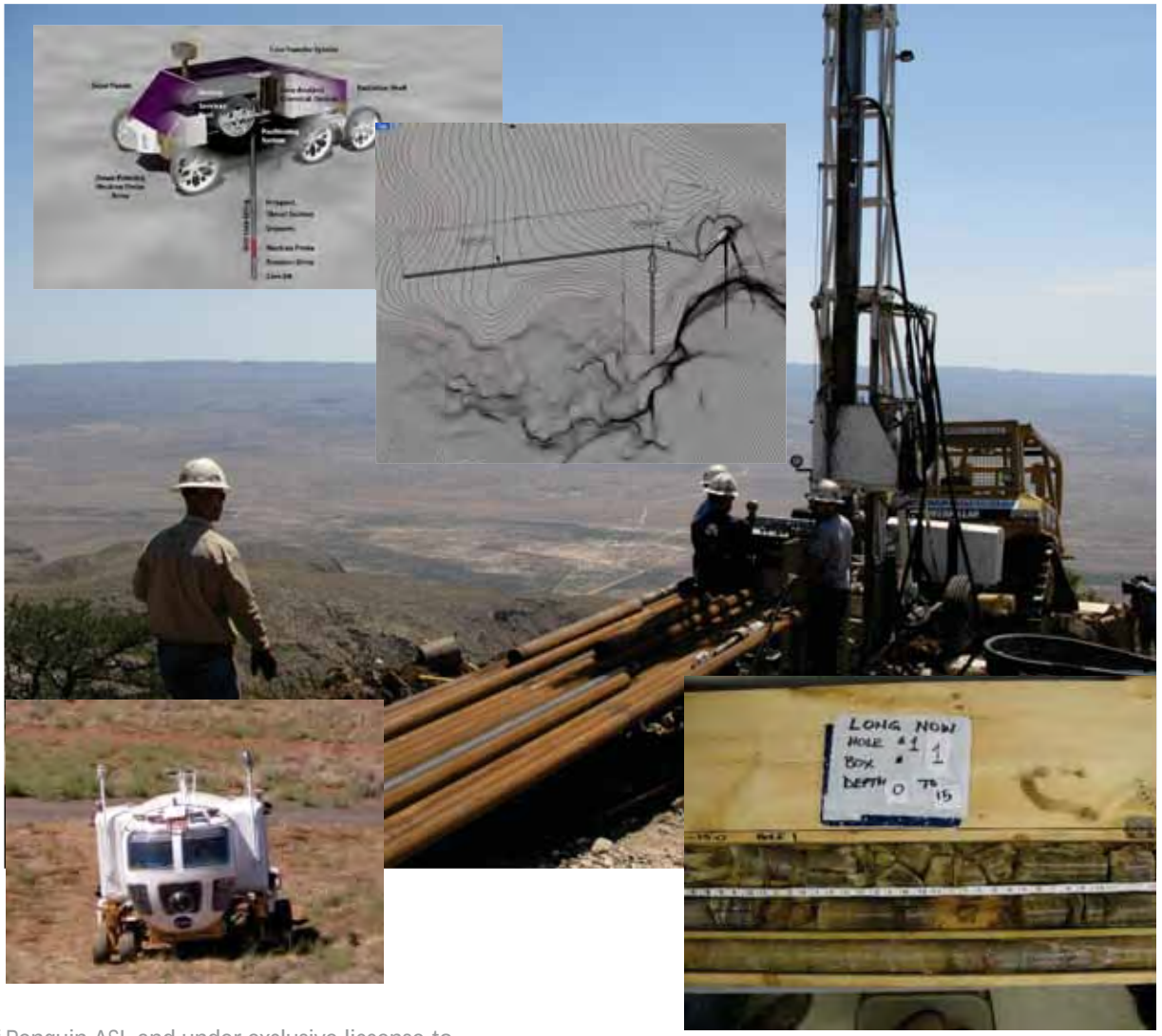
- 1995-2000 Mining Automation Program
  - Consortium lead by Inco (under Baiden leadership) with
    - Tamrock, Dyno Nobel and Canadian Government
    - **$50 million US investment**
  - Research Mine established 1995
    - Objective was the create a telerobotic mining pilot plant before full implementation in business
    - Tested each mobile robotic system to determine performance in actual production conditions
    - **$250 million investment in overall mining R&D**

Mining Automation Program

- 1995-2000 Mining Automation Program
- The work consisted of
    1. Developing high bandwidth networks to cover underground mines - patented
    2. Sub-Surface/GPS denied positioning systems – patented
    3. Several Mining Robots
        1. Tunneling robots
        2. Production Robots
    4. Implemented and field tested
- Outcomes of the work included
    - 10:1 labour savings ratio with 15 teleop employees and 5 teleop workstations
    - 7 types of teleautonomous robots (exploration drills, tunneling drills, haulage loaders, truck, Longhole drills and more.) with a total of 30 robots
    - Over 75 man-years of teleop experience with variable latencies from 0.35 msec. to 2 sec.

Exploration

- Exploration Drilling
  - Responsible for 20 Diamond drilling working the Inco orebodies
  - 750,000 feet of diamond drilling per year to exploration one asteroid hit on earth
- Concepted and build Automated Diamond Drilling now sold to the mining industry
- Performed the Diamond Drilling and rock analysis to build the LongNow Clock Chamber for Hillis and Bezos
- Setup the Lunar Exploration Plan for Shackleton Energy including this new patented exploration rover
- Attended NASA's Desert Rats and participated in Mars exploration mission control
  - Asked to assess Mars exploration process and discuss how it could be automated



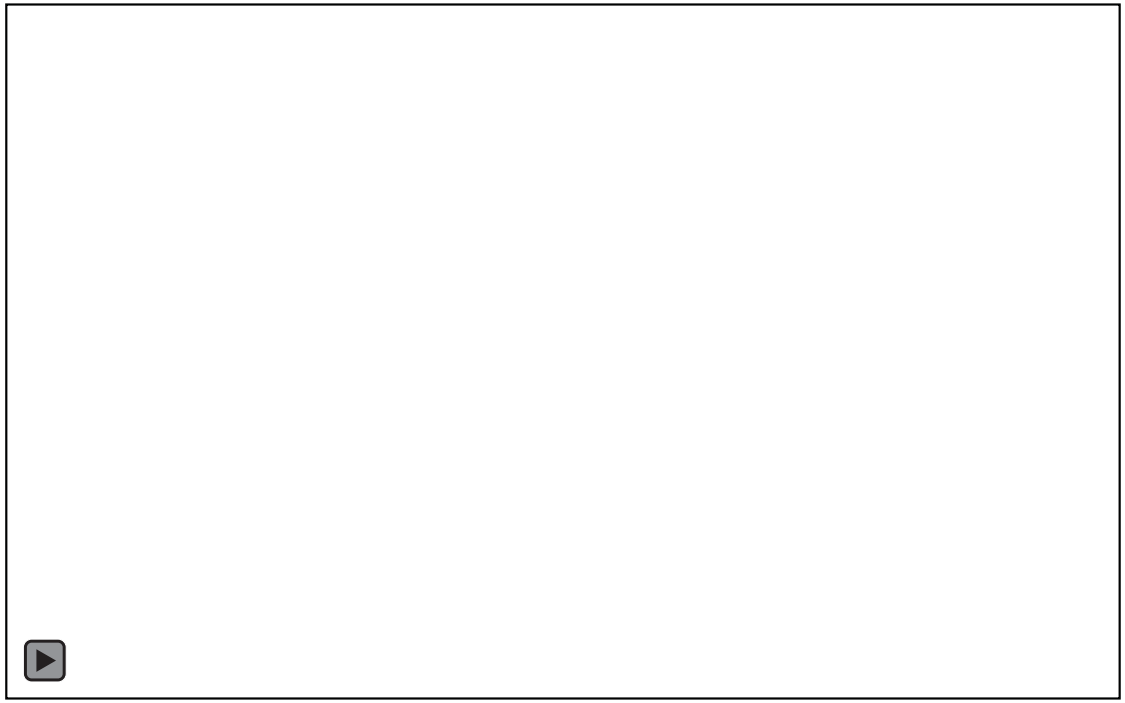
Mining Technology is going through a major transformation

- Key Drivers are:
  - Networking and Positioning
  - Artificial Intelligence
    - Advanced Sensing
    - Pattern Recognition
    - Emulated Reality
    - Robot Coordination
    - Cooperative Robotics

Robot Mapping and Surveying

Penguin's patented underground mapping technology can gather geospatial information in GPS denied environments

- Our latest innovations enable high-precision localization for mining and surveying robot control in a cost effective manner
- Applications of this technology under commercial development include subway and abandoned mine mapping, sewer inspection and mapping and US Navy navigation,



CNC Robotic Mining System

CNC Mining TeleRobot

- Features
  - CNC robot that uses meta-mining (gaming technology) information gathered by scanning an area where personnel cannot enter
  - Arms 10 metre) that reach into no-go areas to drill and load explosives to remove blockages
  - Full teleop control from 500 metres away in an underground tunnel using patented optical networking technology

NASA Lunar Digging Competition


Teleoperation of Digging Robot


Mining Digging Machine


Penguin designed Lunar Digging Robot

Lunar Mining
Penguin has developed these concepts from our proprietary work done for Canadian Space Agency our Mission Team from a senior miner's perspective

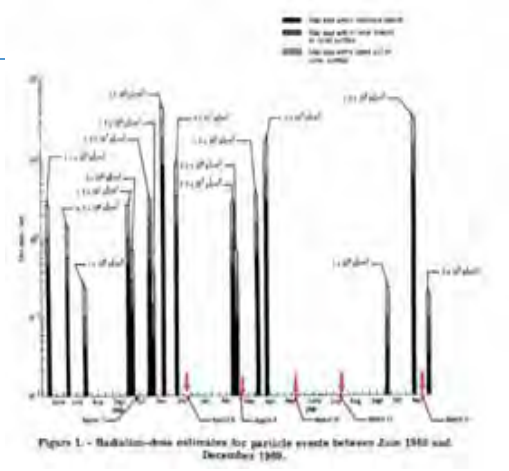
Space excavation and mining techniques informed by terrestrial and lunar work to date

Lunar Mining Challenges

(Each a potential showstopper)

Radiation

- Apollo proved radiation absolutely needs to be dealt with
- Approach:
  - Minimize humans on Moon
  - Maximize use of telerobotics
  - Underground ops and habitats



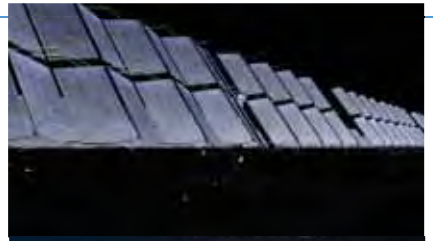
Gravity

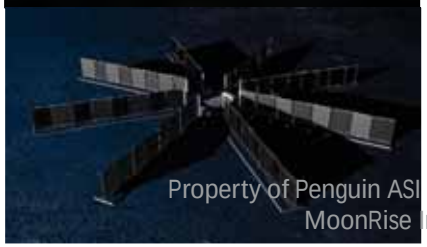
- 1/6 earth gravity
- Gravity single most important factor in earth mining

- Approach:
  - Use more massive equipment than terrestrial mining or load with regolith
  - To get equivalent terrestrial forces, equipment needs to be wedged or connected to lunar crust

Temperature

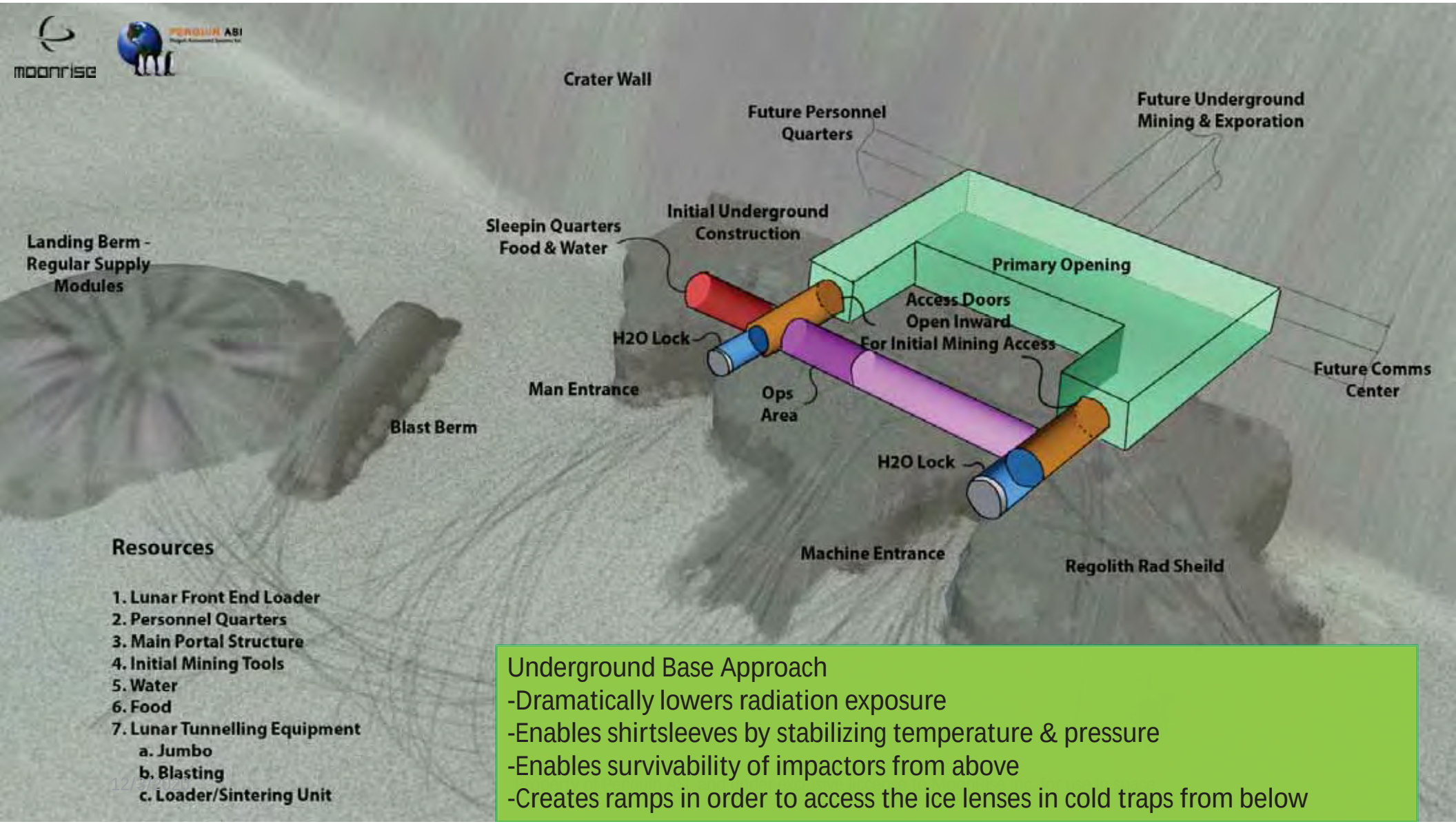
- 30 Kelvin, -230° C
- 3x colder than coldest earth mining
- Approach:
  - Underground operations
  - Energy source to maintain equipment
  - Solar short-term, nuclear power long term





No Atmosphere

- Must create new processes or generate enclosed atmosphere
- Water vaporizes if exposed to sunlight
- Approach:
  - Underground vs. strip mining
  - Environmental containment



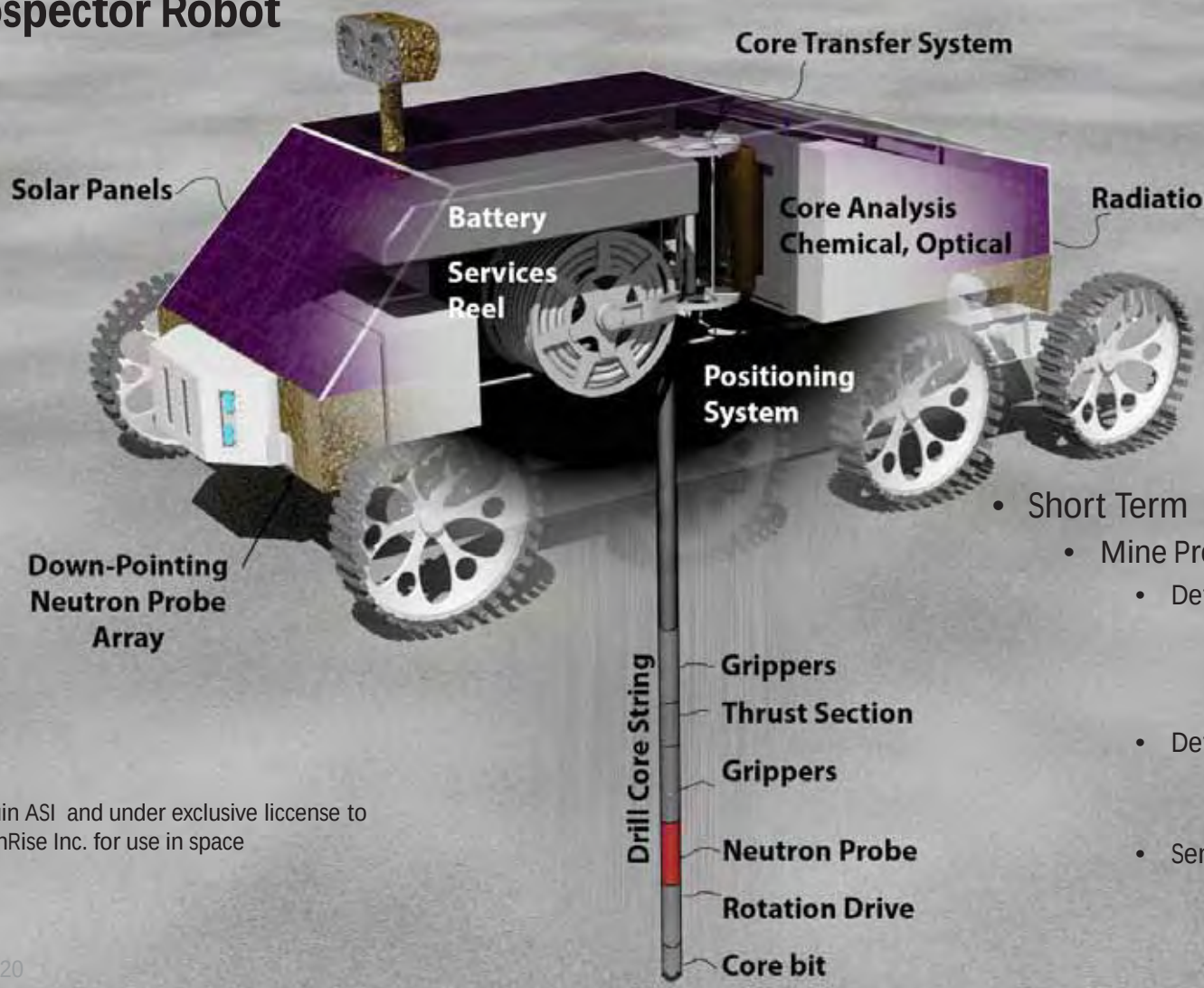
Underground Base Approach
-Dramatically lowers radiation exposure
-Enables shirtsleeves by stabilizing temperature & pressure
-Enables survivability of impactors from above
-Creates ramps in order to access the ice lenses in cold traps from below

Initial Shelter

- Assume lunar construction is done from earth
  - MAP and “optical communications” have overcome latency and bandwidth challenges using 500 mb/s plus and early 386 systems
- Cryogenic-compatible components are made from what we mine today on earth
- Overcome wear and abrasion challenges – requires supply chain
- Solve deep drilling to understand lunar composition below regolith

Terrestrial Control Centre

Lunar Prospector Robot

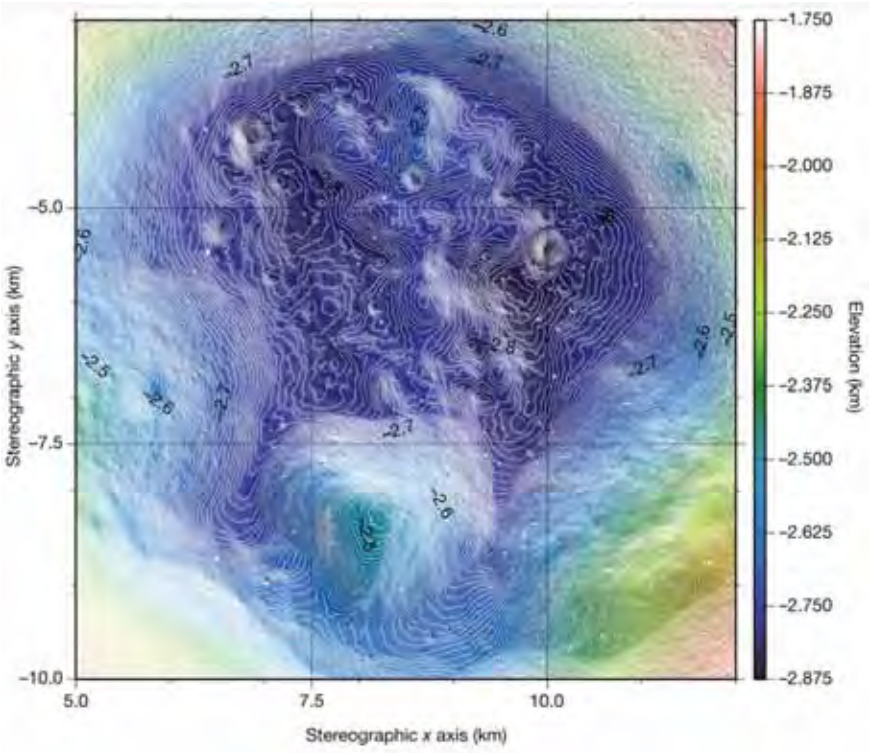


Goals

- Short Term
  - Mine Prospecting Robot
    - Determine Water
      - Location (drilling depth 100 m)
      - Quantity
      - Quality
    - Determine Crater Characteristics
      - Rock/Regolith Physical Characteristics
      - Rock/Regolith Chemical Characteristics
    - Sensing Elements
      - Spectra Analysis
      - Compaction

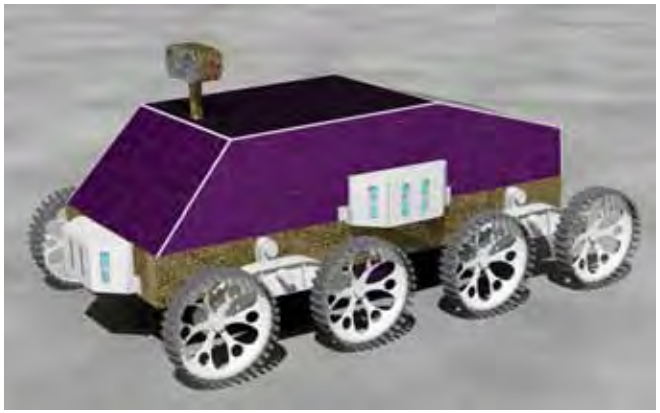
Prospecting and Exploration - Objectives

1. Explore for lunar H_2O, CH_3, NH_4 and other volatiles of interest;
2. Determine quantities, quality and geostatistical variance;
3. Create a database of known and unknown information needed to determine a feasible mining, processing and sustainable economic plan;
4. Define the technical requirements for a shirtsleeve underground human lunar facility as well as underground lunar ice mining;
5. Conduct a series of robotic site assessments so that surface & underground habitation and mine planning can begin for an early manned lunar base



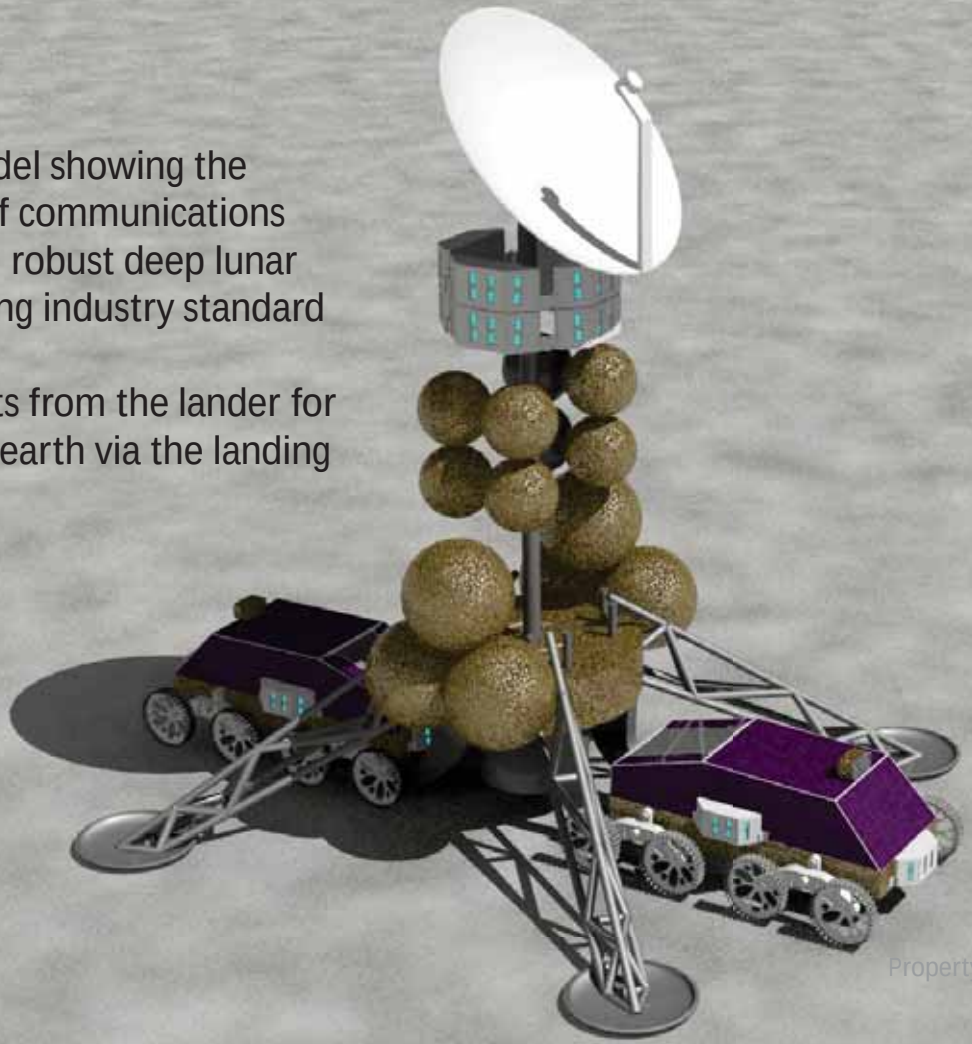
Lunar Teleoperation Command Station On Earth

- INCO MAP and Penguin ASI have demonstrated telerobotic mining is feasible
- The technology is moving rapidly to commercial deployment in terrestrial mining, civil infrastructure and agriculture application
- Numerous space a lunar applications will become enabled by these terrestrial industrial capabilities



Earth to Moon
Teleoperation Feasible
(3 second latency to and from the moon)

Conceptual 3-D model showing the future integration of communications systems that enable robust deep lunar drilling using a mining industry standard grid pattern
Deploying the robots from the lander for Teleoperation from earth via the landing device initially



After the successful measurement, delineation and 3D mapping of minerals and volatiles of interest"

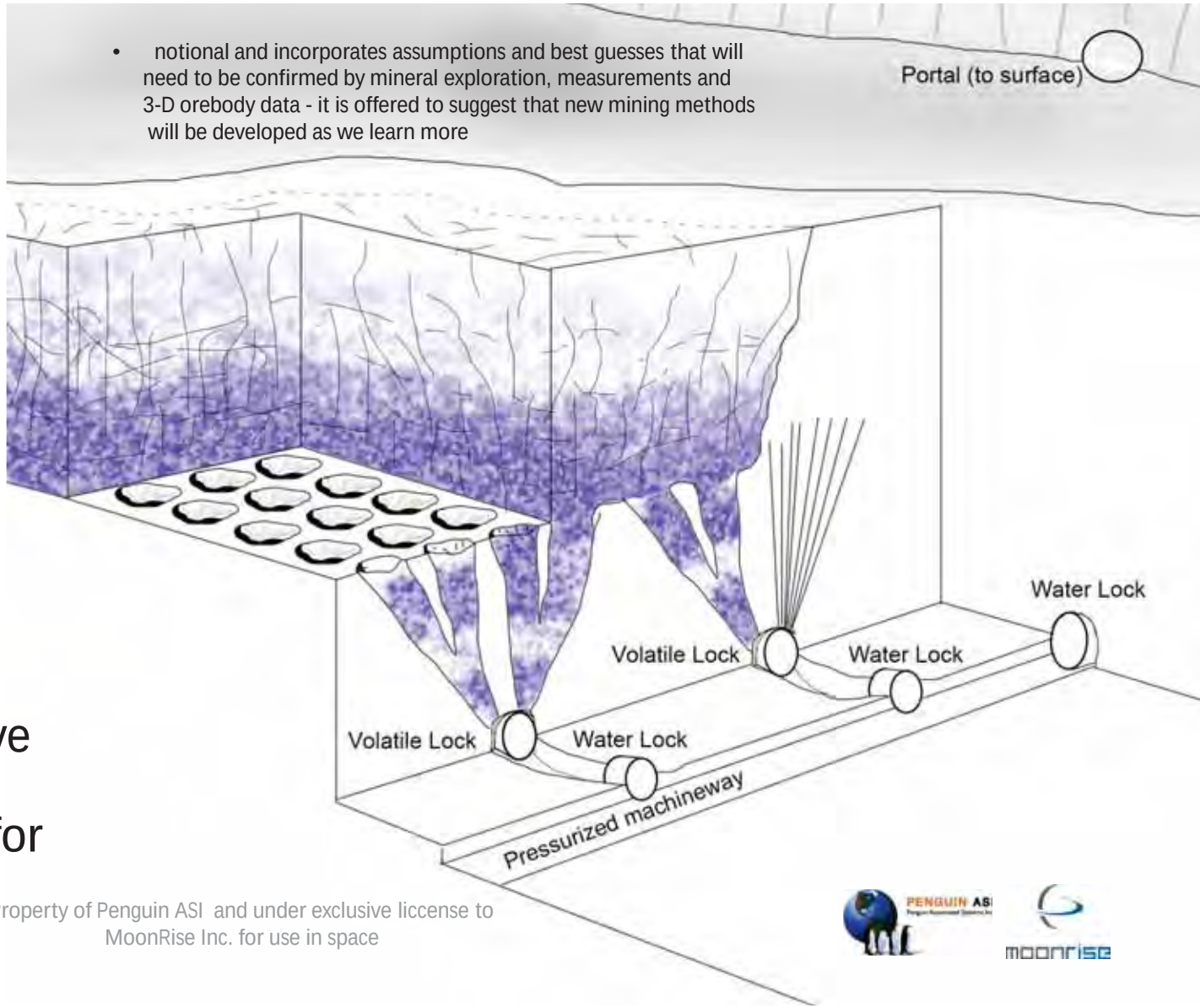
Lunar Teleoperation Command Station

- Remote operation of underground excavation and tunneling equipment was demonstrated at a mine conference in Toronto in 1993, where operators successfully excavated and loaded ore onto a haul truck while encumbered with 1.2 seconds of latency.
- Operators later demonstrated their ability to tolerate up to 4.1 seconds of latency with minimal loss of performance

Earth to Moon
Teleoperation Feasible
(3 second latency to and from the moon)

Block Cave Mining of Crater

- Crater bottom regolith self-breaks from being undercut with lunar gravity
- Ore moves to mined conical bins
- H_2O locks protect the atmospheric lock in the mining area
- Mineral heated to remove H_2O
- Purify and change state for shipping

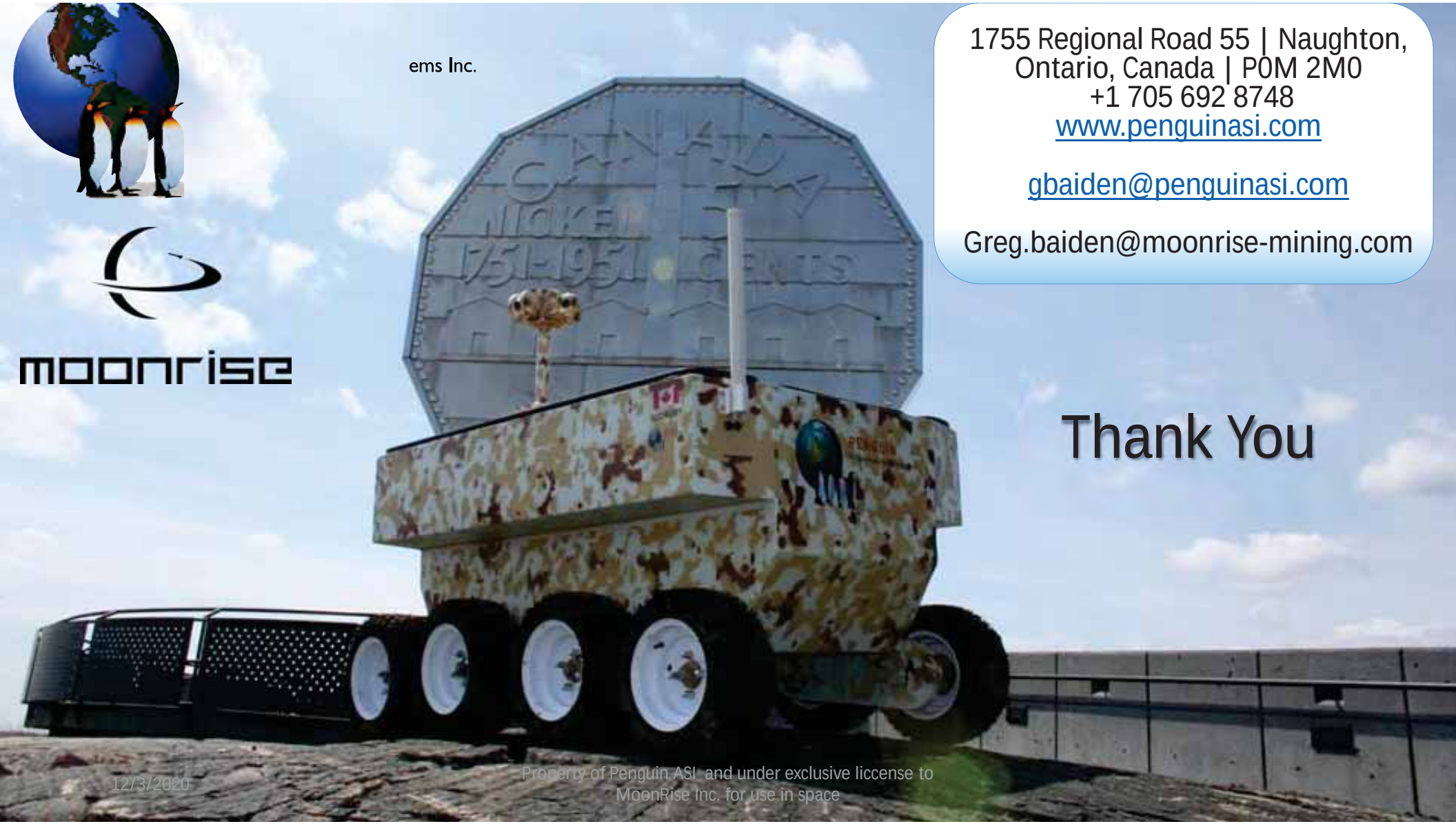


What do we need?

- Proper Prospecting and Exploration
  - Surface regolith (soil) geotechnical measurements
    - Ground truth
    - Variability of regolith characteristics
  - Sub-Surface features including volatile lenses and bedrock
    - Core Analysis
    - How similar is the rock to Earth?
- Customers
  - What products?
    - Short term – Water? Propellants? Consumables? Building materials
    - Long term – Metals, Nuclear etc.
- Support
  - Product requirements and contracts to buy products from companies like MoonRise can allow generating market capital

Summary

- An initial plan for the establishment of an underground lunar base and a mine plan has been developed
- This plan will occur provided polar volatiles of sufficient scale and quality are found
- If the scale is sufficient a further detailed requirements analysis for the establishment of an underground man-rated lunar base as well as the associated underground mine planning will be expanded upon
- This initial plan was started by the mining industry under CSA contract
  - The Initial plan identifies “show-stopper” problems and methods to mitigate them proving concept feasibility.



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Thank You

International Institute for Space Mining

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"Industry led government supported partnership"