



Geology Training for Artemis Missions

National Academies Panel on Lunar and Planetary Sciences for Key Non-Polar Destinations Across the Moon to Address Decadal-level Science Objectives with Human Explorers

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Topics

- Training Plan Overview and Background
- Why Train Astronauts in Geology and Field Methods
- Geology Training Plan: Who is the training team
- Geology Training Plan: What is the content
- Geology Training Plan: Where we train crew
 - Field Details
- Geology Training Plan: When – Notional crew schedule overview for geology and EVA skills
- Geology Training Resources: Partnerships, Gear, Resources, Facilities
- Artemis Geology Crew Training Status and Work to Date
- Summary

- Artemis geology training builds on the legacy of Apollo and Apollo lessons learned
- We train crew to be scientists on the Moon, with the skills to operate in a discovery-based environment
- Artemis Geology Training Team partners closely with the xEVA Trainers in JSC Flight Operations Directorate
 - Focus on skill-building for **integrated science and science operations**

We have 3-phase geology training model for astronauts: build the geology knowledge base across years, starting with incoming Astronaut classes

- Phase 1: Formal training program with new classes, spread over 2 years
- Phase 2: Training provided to unassigned crew for analog testing events, other opportunities
- Phase 3: Artemis assigned crew training (landing site agnostic)
 - Detailed lunar science classes - science questions, planetary processes, sample science
 - Site-specific training, traverse planning and operations
 - Field trips: Geology, field methods, and integrated geology and surface operations

Phase 1: Laying the Foundation

New Astronaut Classes

- JSC Classroom Training (80 hrs)
 - Geoscience Fundamentals
 - Earth and Planetary Systems
 - Planetary Science & Missions
- Field Training (80 hrs)
 - Established NM and AZ locations
 - Basic Geo Mapping & Traverse Planning
 - Sampling & Traverse ConOps
- Expeditionary Components



Phase 2: Building Skills

Before/Between Flight Assignment

Lunar Fundamentals

- Lunar Classroom Content (32 hrs)
- Field Principles (Flagstaff Geo101) (28 hrs)

Lunar Testing

- Lunar Hardware Testing (NBL, ARGOS, RY)
- Lunar Field Tests like JETT (Joint EVA Test Team)

Proficiency Training

- Analog Mission Opportunities
 - PANGAEA, NEEMO, DRATS, CAVES, etc.
 - PSD-funded field opportunities (e.g., SSERVI, PSTAR, GIFT)

Phase 3: Artemis Crew

Mission Science Training, L-24 mo.

- Advanced Lunar Science Classes
 - Surface and Orbital
- Field training (5 locations)
 - Includes Science & Sci/Ops Sims
- Mission-specific Science
 - Science Traverse Planning
 - Payloads



ISS

- Crew Earth Observation



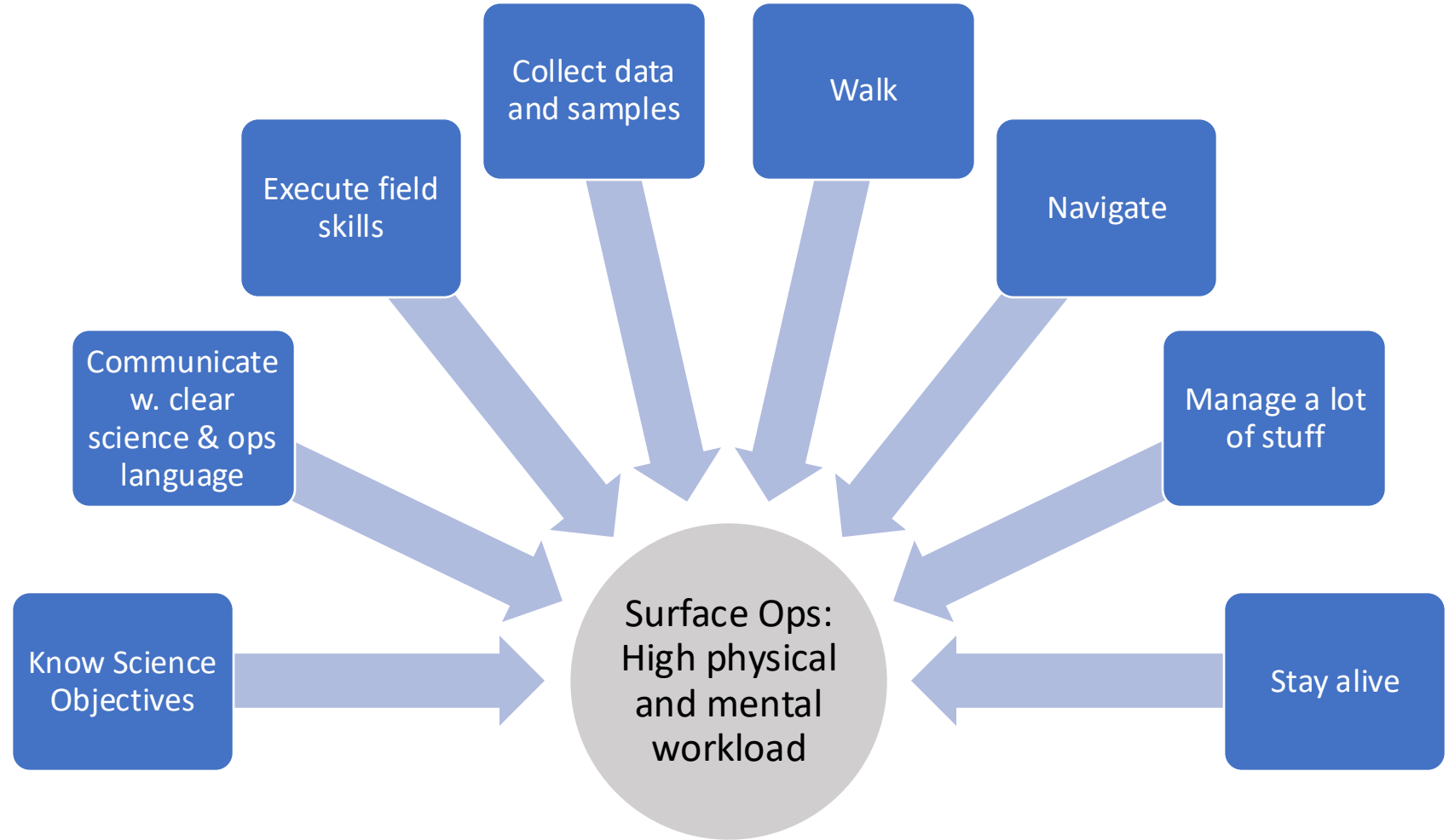
Why

Geology and field training enables mission success and crew safety

- Astronauts on the Moon's surface are the field geologists; they are the brain-eyes-hands-feet required to accomplish lunar science objectives

How

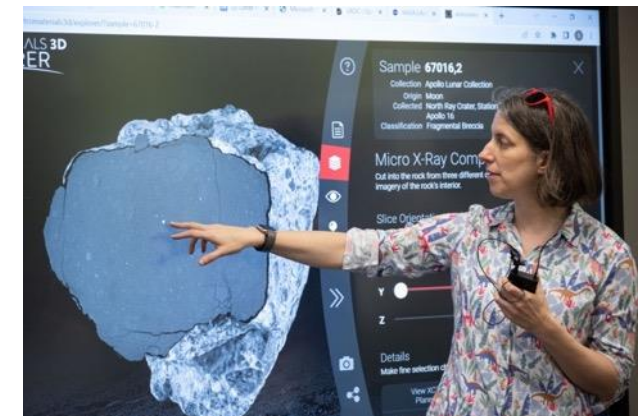
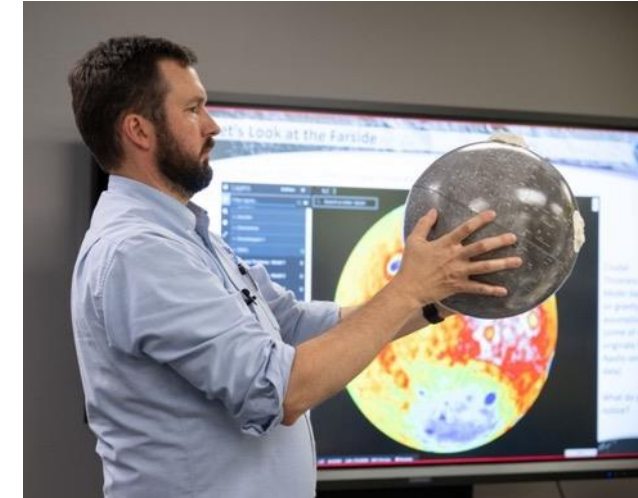
- Crew must have confidence in their geology and field skills and have geology "muscle memory"
- Proficiency and confidence come from repeated exposure to geology and field principles and skills
 - In the field early and often
 - Diverse and challenging field settings
 - Use skills in all training environments



NASA's Core Geology Training Team for Artemis

Team has been working content for ~4 years

- Dr. Cindy Evans – NASA Artemis Internal Science Team Lead for Artemis Geology Training
 - Dr. Sarah Noble – Artemis Lunar Science Lead
 - Dr. Noah Petro – Lunar exploration, Artemis III Project Scientist
 - Trevor Graff – Artemis Testing and Field Lead
 - Dr. Juliane Gross – Lunar Samples Lead, Artemis Curation Lead
 - Dr. Jen Heldmann – Lunar Volatiles Lead, Artemis 3 Geology Team
 - Dr. Jacob Richardson – Lunar Interior Processes, Field Team Member
 - Dr. Tim Stubbs – Lunar Environment (and Helio and Astrophysics)
 - Dr. Kelsey Young – Impact Crater Processes and Field Lead; Science Ops Lead
 - Scott Wray – NASA xEVA Training Lead
- Includes experts from NASA, other agencies & institutions to build develop content
 - Many team members have academic teaching experience and decades of experience in crew training, testing, and field methods



Geology training plan is included within the Flight Operations Directorates (FOD) planning process

- FOD is responsible for all crew training and coordinates with all training partners: e.g., science, Orion spacecraft, ground systems, hardware vendors (landers, suit), international partners
- We coordinate directly with FOD's Chief Training Officer (CTO) and the Artemis Training Panel for overall mission training direction and scheduling
 - Geology crew training requirements provided to FOD
 - We work with FOD for bookkeeping and scheduling
- We partner with the Exploration Extravehicular Activities (xEVA, or space walk) training office within FOD for lunar surface and science operations training
- FOD defines the crew training ground rules:
 - Artemis III is a test flight with multiple mission priorities
 - Schedule constraints: length of training (X months), allowable hrs/week training per person
 - Specific crew training assignments by role (training for surface crew, orbital crew, back-up surface crew)
 - Travel constraints (numbers of trips and trip cadence)
 - Competing training priorities and schedule drivers (e.g. availability of training hardware)
- Surface traverse planning and training: late in training flow, based on site selection timelines
 - Dynamic timeline requires a **well-trained crew who are confident in their lunar geology and field skills, regardless of landing site**

PHASE 3

Assigned Crew Training

Mission Specific
Science Training (Launch-24 mo)

Artemis

- Advanced Classroom (~110 hrs)
- Fieldwork (5 locations)
- Dedicated Surface Ops Sims
- Mission-specific Science/Ops (~110 hrs)
 - Science Traverse Planning
 - Payloads
 - Orbital Observations



NASA's geology & surface training plan includes

- Field training and integrated sims: Skill building over 5-7 deploys
- Classroom training, Year 1: fundamental lunar processes
 - Lunar fundamentals: lunar exploration history and results, major scientific questions, introduction to lunar processes and the importance of samples, take-away messaging
 - Science operations
 - Impact processes
 - Lunar interior processes: deformation and volcanism
 - Lunar volatiles
 - Lunar environment
 - Lunar samples
- Classroom training and activities, Year 2: Artemis science and science operations (~100 hrs)
 - Refreshers, mission updates
 - Mission science and Orbital observations
 - Surface payloads
 - Landing sites – overview, geology
 - Landing sites: Surface traverses, traverse conops, geology objectives
- Joint training with xEVA in JSC facilities (rockyard, ARGOS, NBL, VR)

Most members of the crew office have at least 2 weeks field experience and practice at field observations (Look ODD)

ASCAN Training (since 2009)

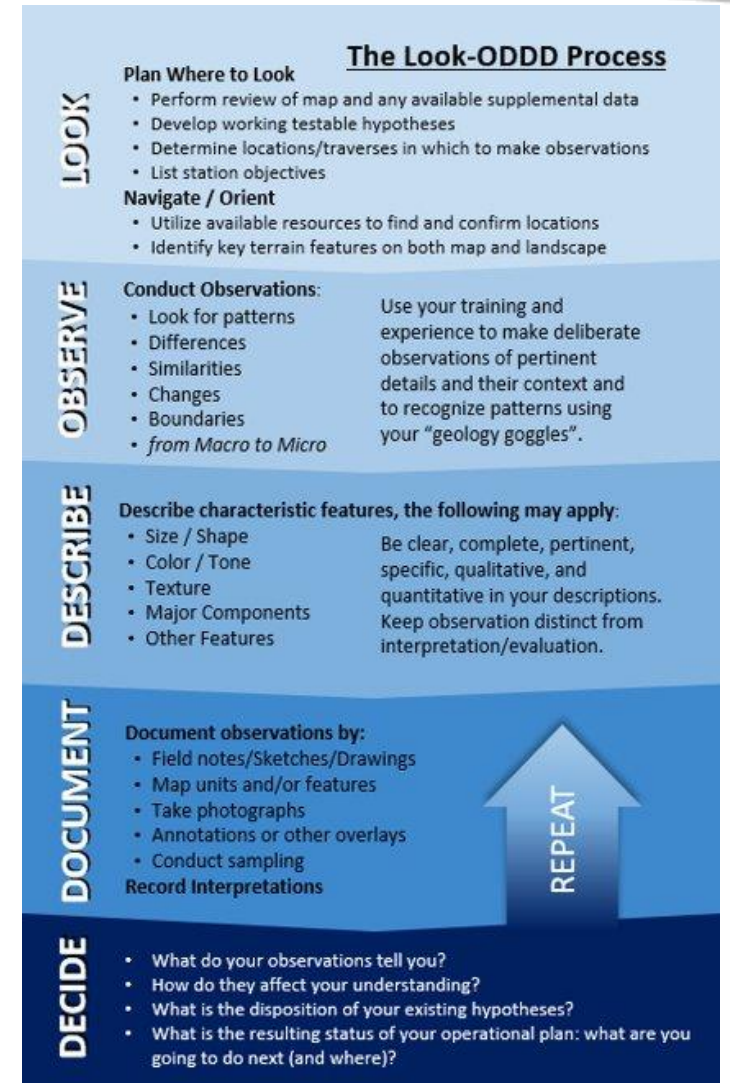
- Fundamental Geology
- Intro to Planetary Science
- 2 weeks of field methods and geological mapping (Rio Grande del Norte, San Francisco Volcanic Field, Meteor Crater, Grand Canyon)
- Introduction and practice of Look ODD

Phase 2 Training

- Analog tests (e.g., DRATS, NEEMO, SeaTest)
- Hardware test campaigns (JETT - Joint EVA Test Team)
- Field assistant opportunities (GIFT, PSTAR)
- SSERVI and PSTAR science-ops research campaigns
- IP opportunities (CAVES, Pangea, Canadian Impact Craters)
- Facility hardware events (e.g. , ARGOS and NBL) with geo content

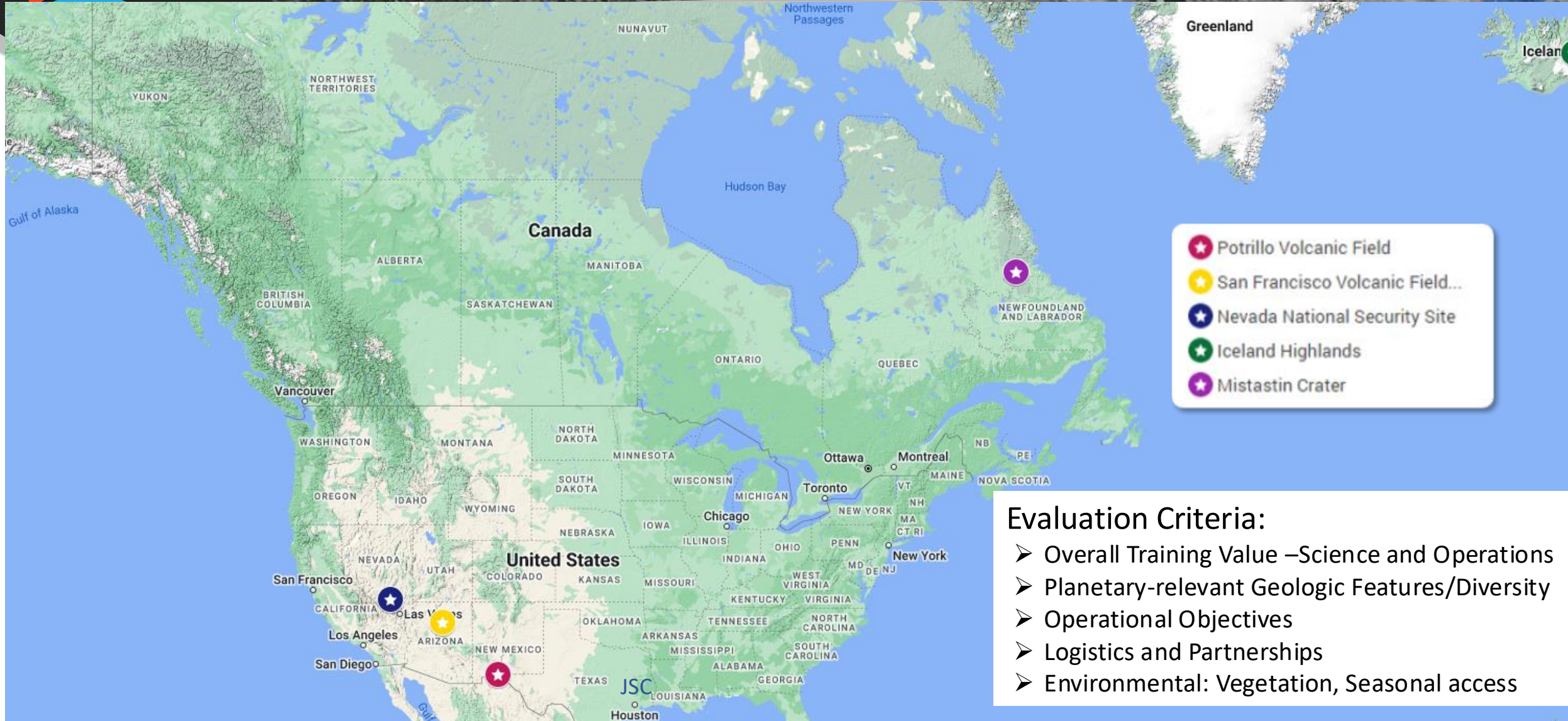
ISS Earth Observations

- Observing a planet and Planetary processes





Artemis Geology Training Plan: Where We Train Crew
















- Evaluation Criteria:**
- Overall Training Value –Science and Operations
 - Planetary-relevant Geologic Features/Diversity
 - Operational Objectives
 - Logistics and Partnerships
 - Environmental: Vegetation, Seasonal access



Artemis Field Science/Operations Training Locations



Field Training Location	Fundamental Science Training Objectives	Joint Science Operations Training Objectives	Logistics & Planning Considerations (+ = travel days)	Classroom Prereqs	Collaborations and prior work
San Francisco Volcanic Field & Meteor Crater (Flagstaff, AZ) 	<ul style="list-style-type: none"> Volcanic Processes Impact Processes Geologic Sampling Strategies Geologic Observations Instrument Use/Understanding 	<ul style="list-style-type: none"> Mission Scale & Fidelity End-to-End EVA Operations Lunar-like Terrain Traverse Planning/Execution Instrument Deployment Low lighting Ops 	<ul style="list-style-type: none"> Duration: 3+ days Season: April to October Travel: Flight into Flagstaff or Phoenix+2.5 hour drive Lodging: either camping or Flagstaff hotels (~45 min drive to field sites) 	<ul style="list-style-type: none"> Geo O/V Lunar Fundamentals Samples Module 1 Impact processes Science operations for last trip 	<ul style="list-style-type: none"> Established USGS partnership  Established Meteor crater partnership ASCAN training JETT and DRATS heritage –science and ops PSTAR/SSERVI experience Apollo legacy
Kamestastin Crater (Labrador, Canada) 	<ul style="list-style-type: none"> Impact Processes and products Feldspathic highlands Lunar-like Materials Geologic Sampling Strategies Geologic Observations 	<ul style="list-style-type: none"> Mission Scale & Fidelity Station skills Traverse Planning/Execution SFRM/Expeditionary Skills 	<ul style="list-style-type: none"> Duration: 10+ days Season: Aug to Sept Travel: Ingress to site via Twin Otter Lodging: remote camping (100+ miles from nearest facilities/medical) 	<ul style="list-style-type: none"> Impact Cratering Samples Mod 1 & 2 Lunar O/V Field methodologies 	<ul style="list-style-type: none"> Established Western Univ. partnership  Innu community partnership CSA collab potential (2023) Artemis 2 training 
Iceland Highlands (Vatnajökull National Park) 	<ul style="list-style-type: none"> Planetary Processes Geologic Sampling Strategies Geologic Observations Volatiles Instrument Use/Understanding Navigation 	<ul style="list-style-type: none"> Mission Scale & Fidelity End-to-End EVA Operations Lunar-like Terrain Instrument Deployment Traverse Planning/Execution SFRM/Expeditionary Skills 	<ul style="list-style-type: none"> Duration: 10+ days Season: July to August Travel: ~10 hr drive from Reykjavik; ~5hr drive from Akureyri Lodging: tents (except for ingress/egress from Iceland) NOLS-like collabs possible 	<ul style="list-style-type: none"> Volatiles Volcanism and Lunar Interiors Regolith processes Samples Mod 1-3 Station Operations Navigation 	<ul style="list-style-type: none"> Established Iceland connections  GSFC GIFT trips/resources JETT 2 resources Artemis 2 training Apollo legacy 
Nev. National Security Site (Nye County, Nevada) 	<ul style="list-style-type: none"> Impact Processes and products Impacts in basalt and regolith Geologic Sampling Strategies Geologic Observations Instrument Use/Understanding 	<ul style="list-style-type: none"> Mission Scale & Fidelity End-to-End EVA Operations Starship analog Lunar-like Terrain Traverse Planning/Execution Low lighting ops 	<ul style="list-style-type: none"> Duration: 3-6 days Season: Sept-May Travel: Flights into Las Vegas Lodging: group lodging facilities available on location at NSSS Assets: Lighting rig, Core library, imagery 	<ul style="list-style-type: none"> Lunar Fundamentals Impact Cratering Lunar Interior Operations Samples Mod 1 & 2 	<ul style="list-style-type: none"> Established DOE/NNSS partnership  DOE training materials JETT 4 and JETT 7 demonstrated operations Apollo legacy
Potrillo Volc. Field & Kilbourne Hole (El Paso, TX) 	<ul style="list-style-type: none"> Planetary Processes Geologic Sampling Strategies Geologic Observations Instrument Use Features at Appropriate Scale 	<ul style="list-style-type: none"> Station Scale & Science Fidelity Instrument Deployment Traverse Planning/Execution 	<ul style="list-style-type: none"> Duration: 3+ days Season: Jan/May and Sept/Dec Travel: Quick flight from Houston to El Paso; 60 min drive to field site Lodging: motel ~60 min from field site 	<ul style="list-style-type: none"> Geo O/V Lunar Fundamentals Samples Mod 1 Volcanism Station Operations 	<ul style="list-style-type: none"> Established UTEP partnership  SSERVI collab and resources  JETT 1 operations Apollo legacy



Notional Field Flow

- Skills**
- Foundational
- Fundamental Science
- Unique, High Priority Sci.
- Applied Science
- Navigation
- EVA Ops Products
- Orion & HLS Skills
- Suited Skills
- Science Mental Workload
- Sampling
- Payload Deployment
- Photography
- Traverse Execution
- Include EVA FCT
- PAO Relevance

Setting the Base

AZ Flagstaff 1	
Field Science Fundamentals	
Out of 2-yr Assigned Crew Flow	
Training Days	3
Travel Days	1
Field Lead	KEY

Skills	
Foundational	
Fundamental Science	
Science Mental Workload	
Sampling	
Photography	
Include EVA FCT	
PAO Relevance	

NM Potrillo VF	
Tools/Sampling Fundamentals	
Station Skills	
Training Days	3
Travel Days	1
Field Lead	KEY

Skills	
Foundational	
Fundamental Science	
Science Mental Workload	
Sampling	
Photography	
Include EVA FCT	
PAO Relevance	

Skill Building (Ops & Science)

NV NNSS 1	
Crater features	
Crater Scale	
Impact products	
Training Days	3
Travel Days	1
Field Lead	TGG

Skills	
Fundamental Science	
Science Mental Workload	
Navigation	
EVA Ops Products	
Orion & HLS Skills	
Photography	
PAO Relevance	

Canada Kamestastin	
Crater Features	
Impact Samples	
Station Skills	
Feldspathic rocks	
Training Days	8
Travel Days	2
Field Lead	KEY

Skills	
Fundamental Science	
Unique, High Priority Sci.	
EVA Ops Products	
Orion & HLS Skills	
Science Mental Workload	
Sampling	
Photography	
Include EVA FCT	
PAO Relevance	

Iceland Highlands	
Regolith/Ice	
Navigation	
Mission-Scale Ops	
Tools/Sampling	
Training Days	7
Travel Days	2
Field Lead	TGG

Skills	
Fundamental Science	
Unique, High Priority Sci.	
Applied Science	
Navigation	
EVA Ops Products	
Suited Skills	
Science Mental Workload	
Sampling	
Photography	
Include EVA FCT	
PAO Relevance	

AZ Flagstaff 2	
Crater Features	
Traverse Skills	
Payloads Intro	
Tools/Sampling	
Training Days	3
Travel Days	1
Field Lead	KEY

Skills	
Fundamental Science	
EVA Ops Products	
Orion & HLS Skills	
Suited Skills	
Science Mental Workload	
Sampling	
Payload Deployment	
Photography	
Traverse Execution	
Include EVA FCT	
PAO Relevance	

Final, Integrated Sims

NV NNSS 2	
Artemis Ops Mission Sim	
Payloads	
Tools/Sampling	
Training Days	3
Travel Days	1
Field Lead	TGG

Skills	
Navigation	
EVA Ops Products	
Suited Skills	
Science Mental Workload	
Sampling	
Payload Deployment	
Photography	
Traverse Execution	
Include EVA FCT	
PAO Relevance	

AZ Flagstaff 3	
Artemis Ops Mission Sim	
Payload	
Tools/Sampling	
Training Days	5
Travel Days	1
Field Lead	KEY

Skills	
Navigation	
EVA Ops Products	
Suited Skills	
Science Mental Workload	
Sampling	
Payload Deployment	
Photography	
Traverse Execution	
Include EVA FCT	
PAO Relevance	



When: Notional Crew Training Schedule – Joint EVA and Science



Year 1 Notional Lunar Science Training Flow

L-24	L-23	L-22	L-21	L-20	L-19
EVA OV					
Nav OV					
Lunar Science OV	Science Ops OV	Trip 1	Lunar Interior - Tectonic	Samples Pt 2	Kemestastin Trip
Lunar Fundamentals	Station Ops OV	Impact Craters	Impact Craters		
	Samples Pt 1				
EVA/Surface Ops	EVA/Surface Ops		EVA/Surface Ops	EVA/Surface Ops	
L-18	L-17	L-16	L-15	L-14	L-13
EVA Systems			EVA Systems	EVA Systems	
EVA-Sci				EVA-Sci	Lunar Surface P/TV
Lunar Volcanism	Lunar Volatiles	Lunar Geography	NNSS		Science PL 1
		Orbital Observations			
		Samples Pt 3			
		Lunar Environment			
EVA/Surface Ops	EVA/Surface Ops	EVA/Surface Ops	EVA/Surface Ops		
	ARGOS	ARGOS	ARGOS	NBL-Surface Ops	RY- Science PL1

Year 2 Notional Lunar Science Training Flow

L-12	L-11	L-10	L-9	L-8	L-7
EVA Systems	EVA Systems	EVA Systems			
EVA-Sci		Landing Site Traverse		Landing Site Traverse	Landing Site Traverse
				Dust Mitigation	Landing Site Traverse
				EVA-Sci	
	Field-Flagstaff 2	CLPS updates	Iceland Trip	Lunar Sci. updates	
		Science PL 2	Regional Geo Site A		
			Regional Geo Site B		
			Regional Geo Site C		
					EVA AXES
EVA/Surface Ops		EVA/Surface Ops	EVA/Surface Ops	EVA AXES	EVA RY
NBL-Surface Ops	NBL-Surface Ops	Science PL 2 RY		EVA 3 RY	EVA NBL
L-6	L-5	L-4	L-3	L-2	L-1
	EVA Systems		EVA Systems		
EMSS Tools		Landing Site Traverse	Landing Site Traverse	Landing Site Traverse	Landing Site Traverse
		EVA 1 Ops			
			EVA 2 Ops	EVA 3 Ops	EVA 4 Ops
Field AZ 3 Int Sim	Science PL 3		Science PL 4	Science Refresher	Science Refresher
					Lunar Surface Science Objectives
					Lunar Sample Capstone
	EVA/Surface Ops		EVA/Surface Ops		
	EVA/Surface Ops			EVA 3 NBL	EVA 4 NBL
	EVA AXES	EVA AXES	EVA AXES	EVA AXES	EVA AXES

Legend
Joint Classes
Science Classes
Field Training
Systems Classes
Task Classes
Facility Runs



Partnerships: xEVA training Office, USGS Astrogeology, Western University (Canada), UT El Paso, Nevada National Security Site/DOE, Iceland National Parks, Barringer Meteor Crater Company, Bar-T-Bar Ranch (AZ), Babin Ranch, New Mexico Tech/Bureau of Mineral Resources, BLM



Training Gear: Classroom gear (rocks, maps, materials), field gear (camping, safety, group shelters), Command Van and trailer (field communications, data & software, field infrastructure), Artemis Govt Reference Design Tools



Resources & Facilities: GSFC Science Visualization Studio <https://svs.gsfc.nasa.gov>, JSC VR (PIT Lab), ARGOS, NBL, JSC Rockyard



Artemis Geology Training: Work to Date



Lunar Lab

New Astronaut Class Training

- Dedicated lunar science and field training for 2009, 2013, 2017, 2021 classes
- ~75% of current crew office

Artemis Community Training

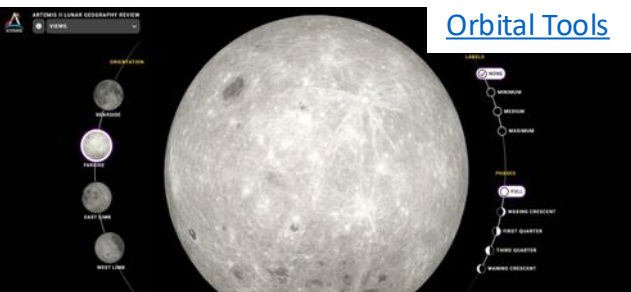
- Lunar Fundamentals: 4 classes, 60 students
- Geo 101 (Field methods for Artemis community): 40-60 students/year (217 students since 2019)



Lunar Fund.

Artemis 2

- Lunar Fundamentals (May 2023)
- Kamestastin (Sept 2023)
- Pre-Iceland Science
- Iceland (July 2024)
- Orbital observations: June 2025
- On-board Observation Tools – Atlas and Targeting Plan
- Preparing for crew simulations that include Lunar pass



Orbital Tools



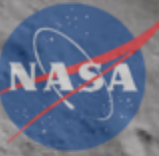
Field: Kamestastin



Field: Iceland



Artemis Geology Crew Training Status



Artemis 3+ (Site-agnostic content) Preparation

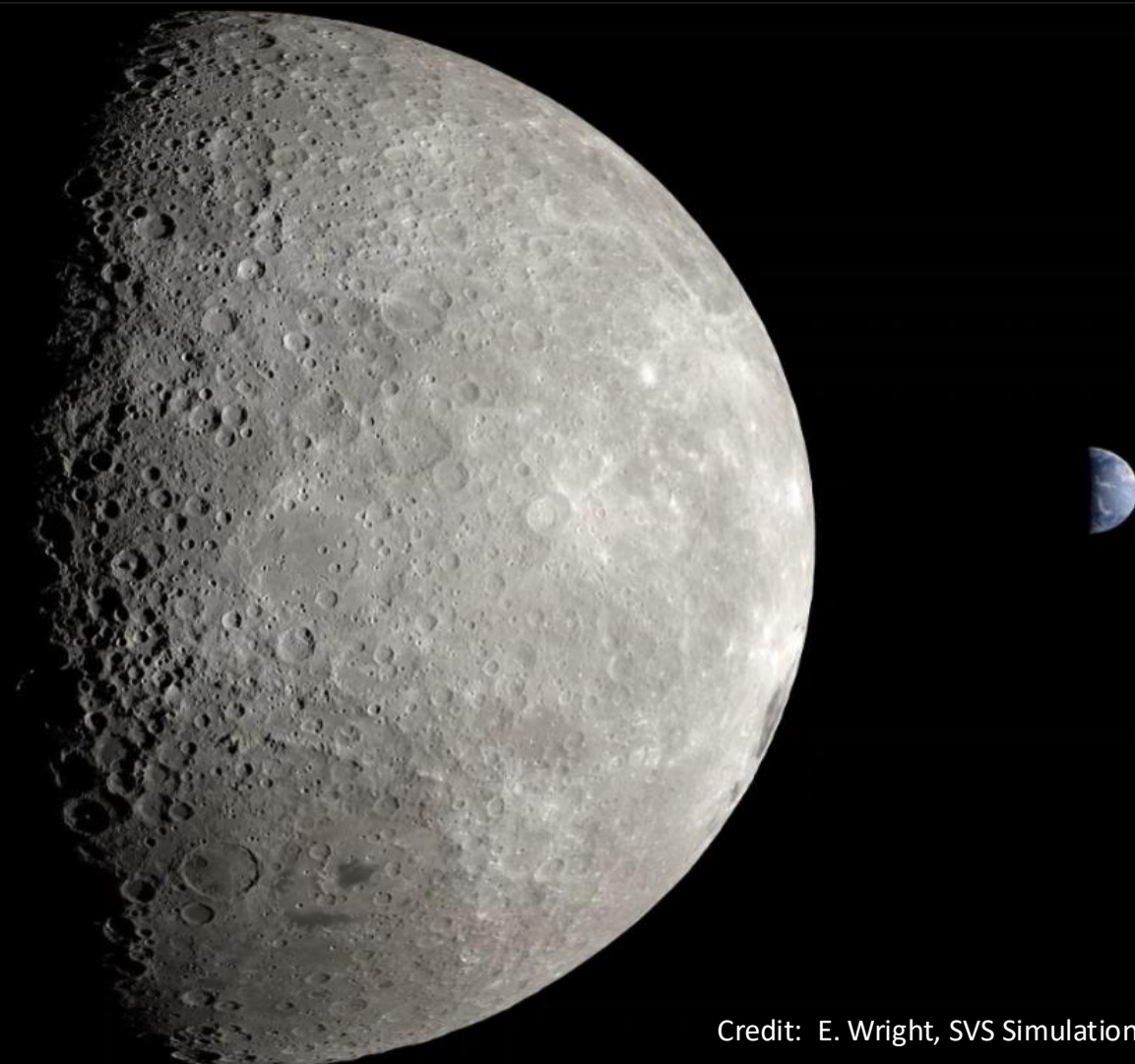
- Detailed tracking of status/readiness for each hour of lunar science training
 - Team is finalizing content development, validating lessons plans, digital content, lab exercises, field objectives and logistics, associated administrative coordination
- Field training readiness includes detailed objectives and plans for each day in the field, additional coordination, logistics, safety and readiness reviews for each site.
- Leverage Artemis 2 training and products: Artemis Orbital Atlas and Targeting Tool
- Analog testing with crew, science team, and flight control team (JETT-5 with NASA/PSD support)
- VR mini-sim 1 at Nobile Rim 1 location with Artemis 3 Geology Team and flight control team
- NASA facility testing (gravity offload and neutral buoyancy lab) with prototype suits and geology tools.
 - Geology tasks, testing includes several from crew office



Summary



- Lunar Science content for crew training for initial Artemis landed missions is being developed
- Content is site-agnostic, focused on building basic geology skills and language
- Crew training includes integrated science (geology) and science operations for surface traverses
- Cross-agency and cross-organization relationships and logistics are solid for supporting training
- For first missions, 5 field areas under development
 - progressively build crew geology, observations, and field operations skills
 - train the diversity of samples and planetary processes expected for lunar exploration
 - includes integrated, multi-day, mission-scale simulation in the field with crew, science team, and flight control team



Credit: E. Wright, SVS Simulation



Back-up



Back Up Information



Historic Training Locations (1963 to 1972) – SW USA



United States



- General (38)
- Apollo 17 (22)
- Apollo 15 (20)
- Apollo 16 (20)
- Apollo 14 (9)
- Apollo 12 (7)
- Apollo 13 (7)
- Apollo 11 (1)
- Apollo 8 (1)

Phinney W. C. 2015

ALASKA

Katmai National Monument (2)

ARIZONA

Buell Park

Camp Verde

Cinder Lake Crater Field

Cottonwood

Flagstaff Region (15)

Grand Canyon (3)

Kitts Peak Observatory

Meteor Crater (4)

Verde Valley

CALIFORNIA

Mojave Desert

Chocolate Mountains (3)

Coso Hills (4)

Medicine Lake (2)

Mono Crater (2)

Orocopia Mountains (2)

San Gabriel Mountains (3)

Ubehebe Craters

HAWAII

Hawaii Volcanics (12)

IDAHO

Craters of the Moon

MINNESOTA

Northern Minnesota (2)

MONTANA

Beartooth Mountains (2)

NEW MEXICO

Capulin Mountains

Cimarron / Philmont Ranch

Jemez Mountains (3)

Potrillo / Kilbourne Hole (3)

San Juan Mountains (2)

Valles Caldera (2)

Zuni Salt Lake (3)

NEVADA

Boulder City Region

McCullough Mountains

Nevada Test Site (10)

Pancake Range

OREGON

Bend Region (4)

TEXAS

Big Bend National Park (5)

Quitman Mountains

Sierra Blanco

Sierra Madera

INTERNATIONAL

Iceland Volcanics

Pinacates, Mexico (4)

Ries Crater, Germany

Sudbury, Ontario, Canada (3)

Medicine Hat, Alberta, Canada

(#) Indicates number of visits to a particular location

Green: Locations visited by current astro corps

Red Text: Proposed Artemis Training locations



Apollo 13 vs Artemis 3 Geology Training



Artemis Field Plan	Duration (Days)	Apollo 13 Field	Duration (Days)
Kamestastin Impact Crater	8	Orocopia CA	8
Nevada Nat. Security Site	6	Mono Crater CA	7
Iceland Highlands	8	Meteor Crater	1
Flagstaff/Meteor Crater	3	Kilbourne Hole	1
Flagstaff sim	5	Hawaii	4
Bonus: Kilbourne Hole	(3)	Flagstaff & Black Mesa	3
TRIP TOTAL	30 (33)	TRIP TOTAL	24

Additional Artemis Geo Training

- Builds on earlier field events
- Lunar science, lunar processes classes and activities (with lab visits)
- Facility training (ARGOS, NBL)
- VR sims

Additional Apollo Geo Training

- Builds on earlier field sorties starting in 1964
- Facility training (e.g., rock yard, Ellington)
- Geology classes

