



UCSB Computer Engineering Capstone

2026



Team



Chloe
Andersen

Team Lead, Display, ML, & Software Integration



Shruthi S.
Unnithan

Speech-to-Text Software & Hardware, Display UI & Controls



Lily
Chen

ML Rock Classification Software



Ilai
Tamari

Speech-to-Text Software & Hardware

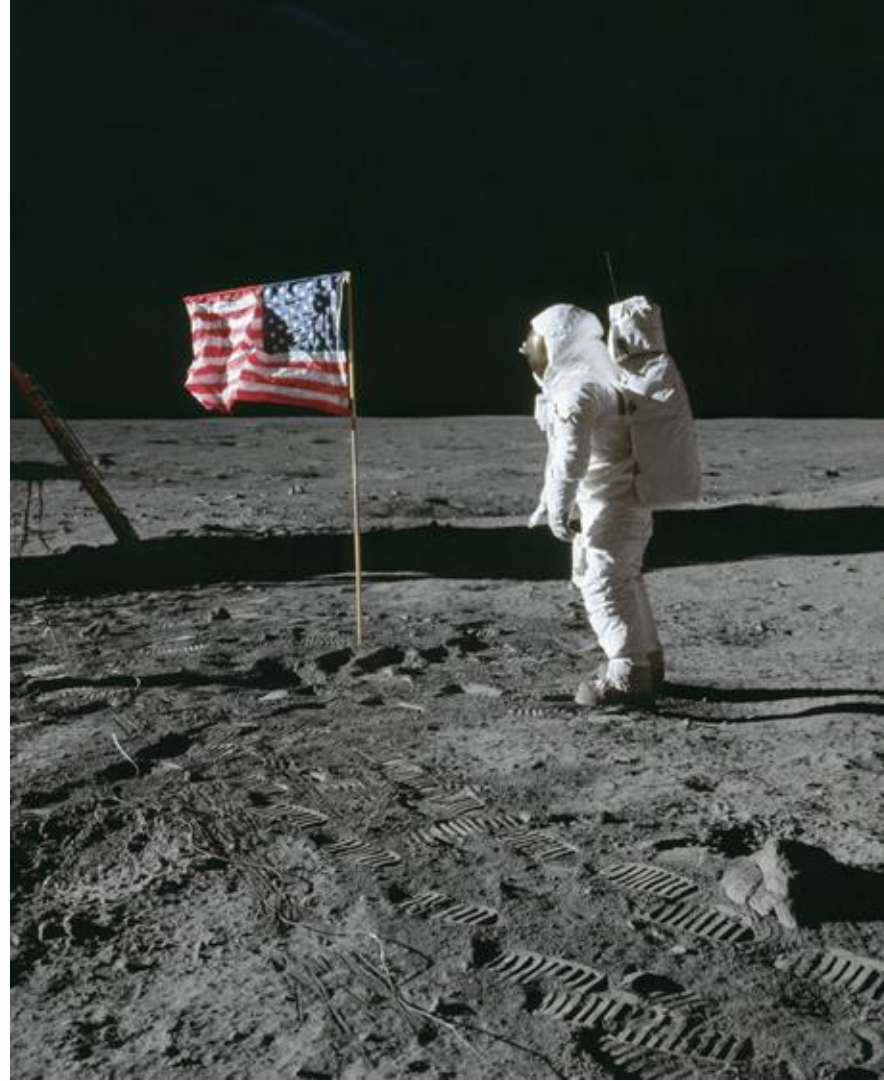


Bruce
Huang

Volume Calculations & Ground UI Software

PROBLEM

Astronauts on EVAs have time constraints & communication delays. Future missions require autonomous decision making.

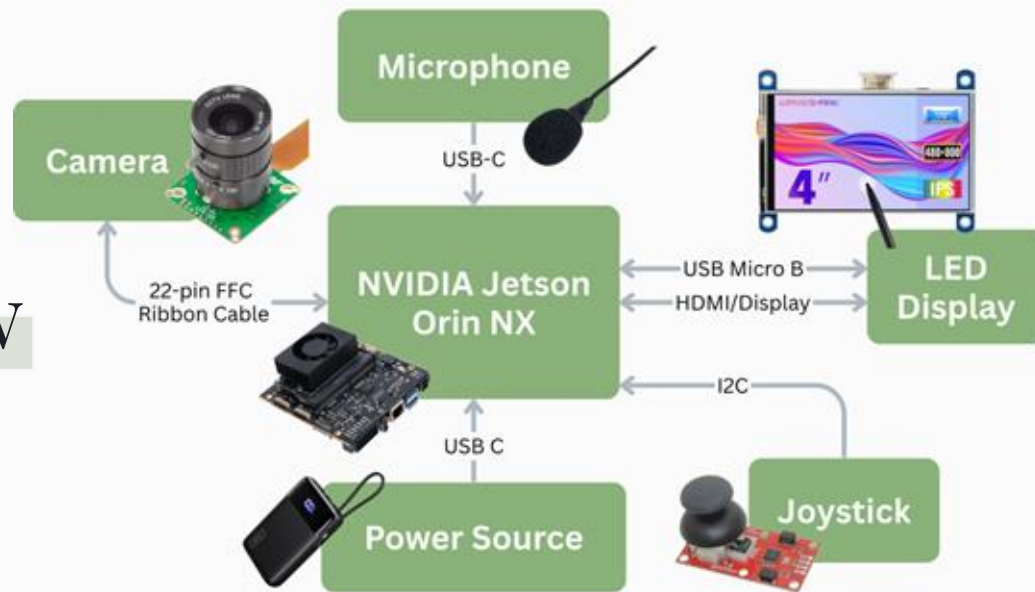


PROPOSED SOLUTION

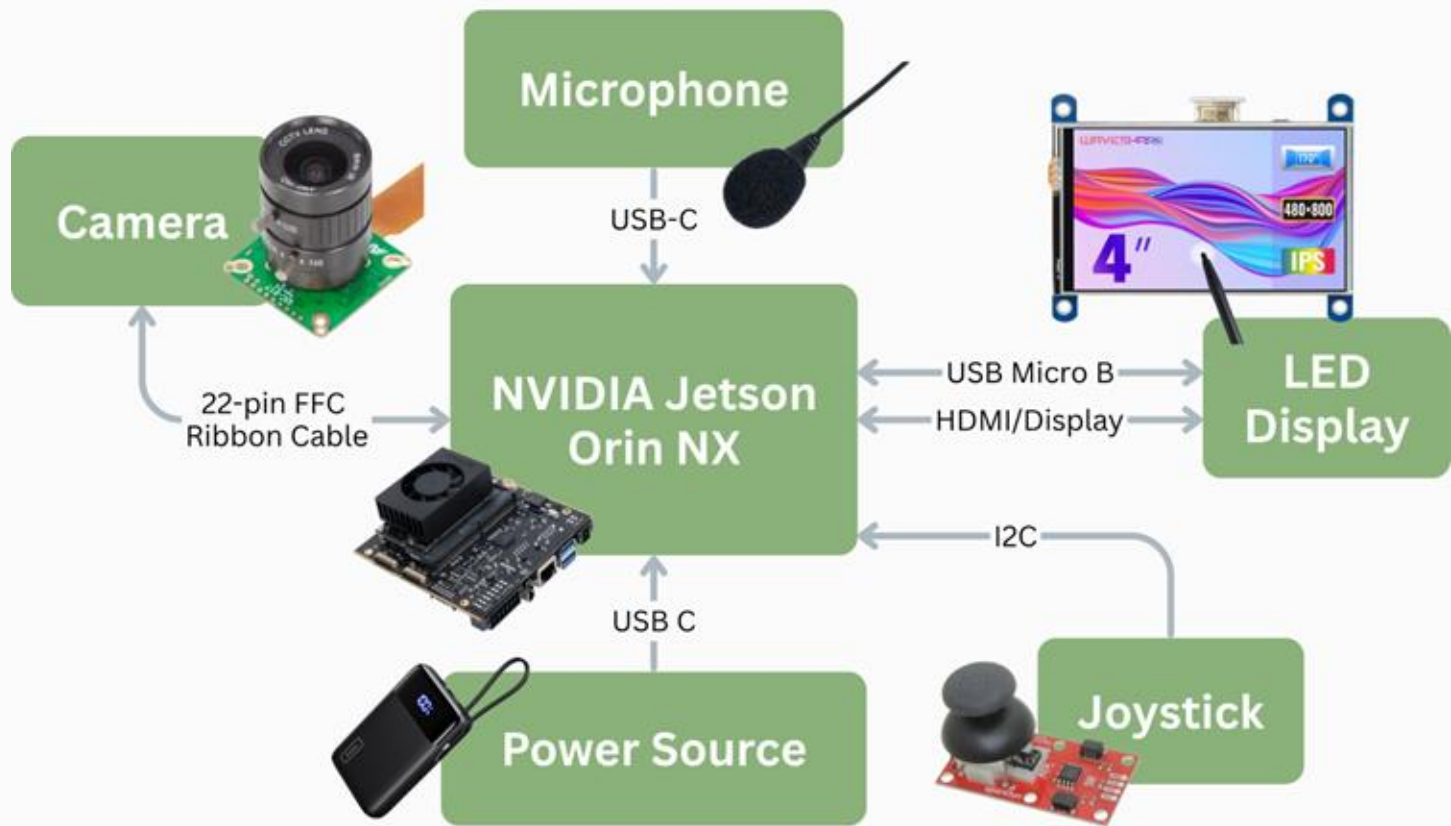
SAGE integrates ML classifications, volume calculations, & voice transcriptions all onto a **single edge device** for fast & autonomous geological analysis during EVAs.



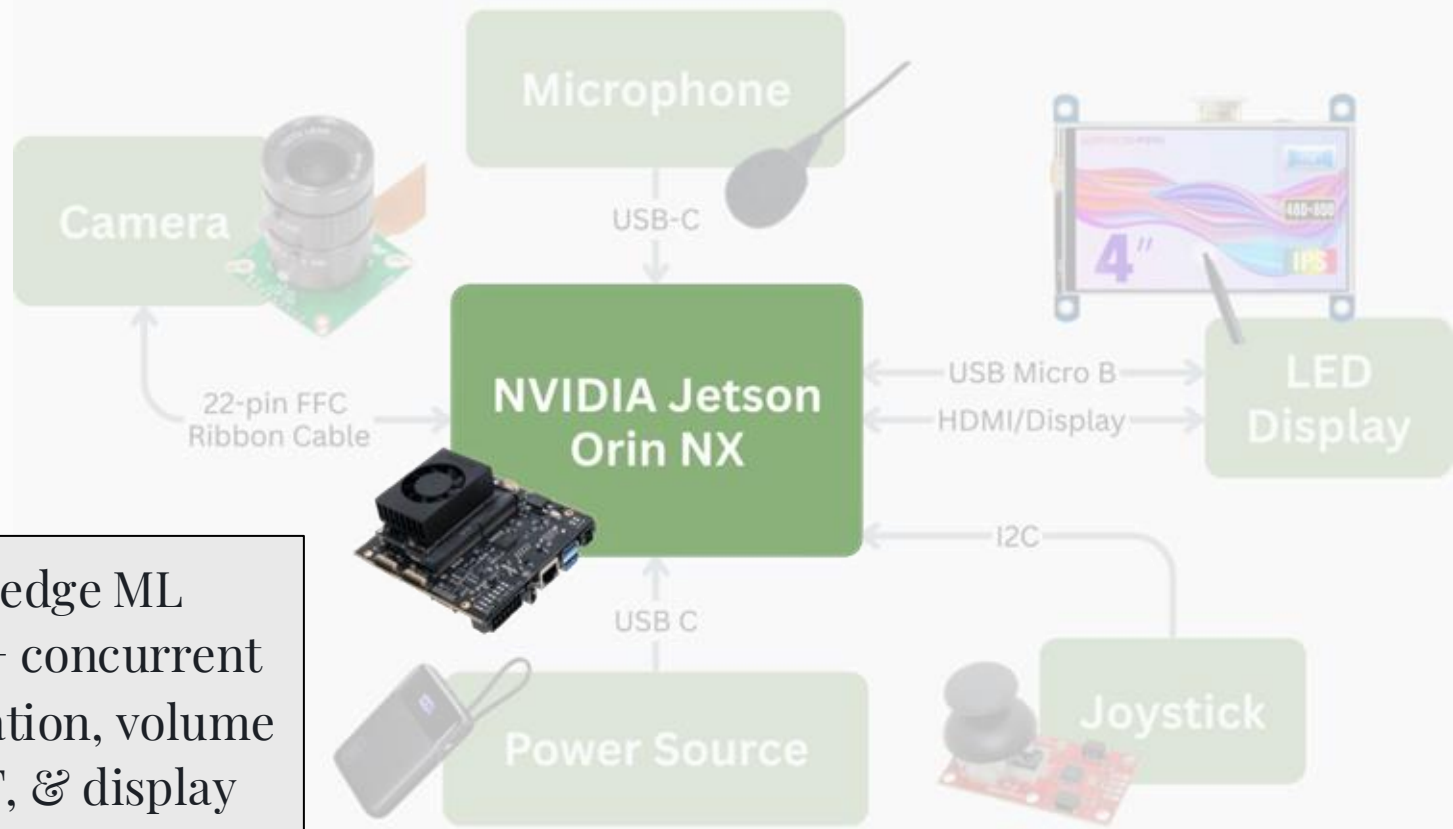
Hardware Overview



Hardware Overview

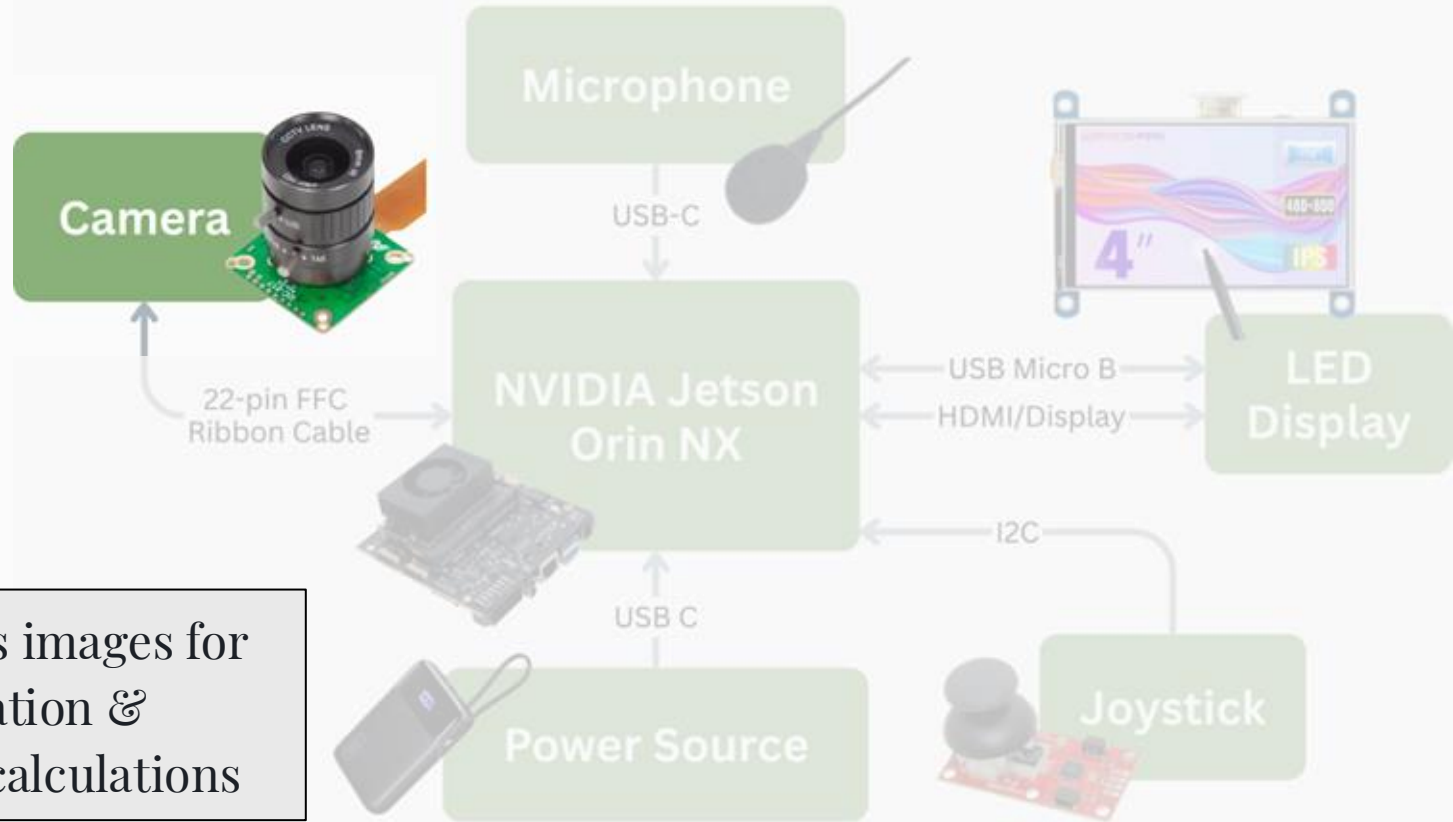


Hardware Overview



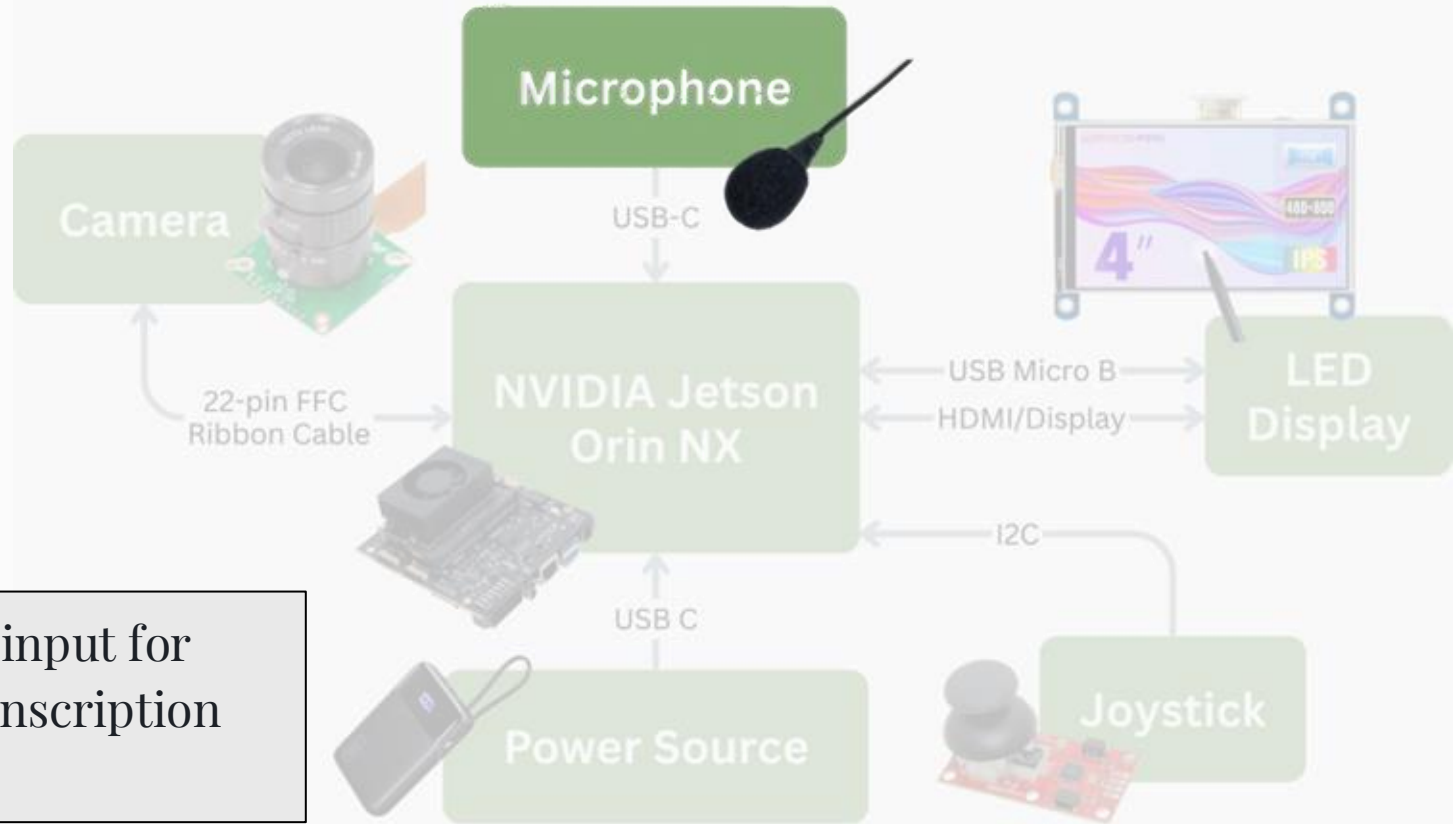
Handles edge ML models + concurrent classification, volume calc, STT, & display

Hardware Overview



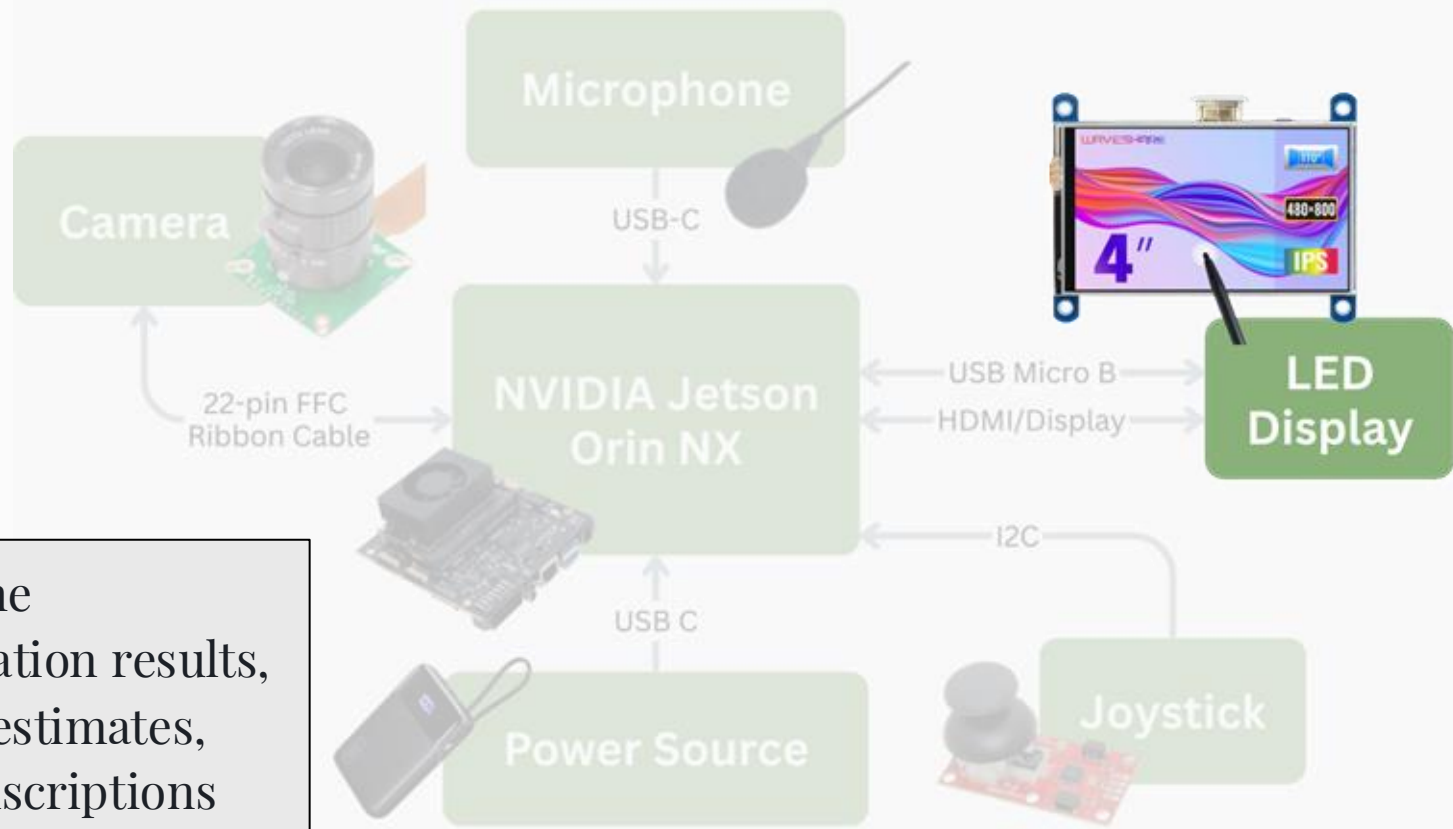
Captures images for
classification &
volume calculations

Hardware Overview



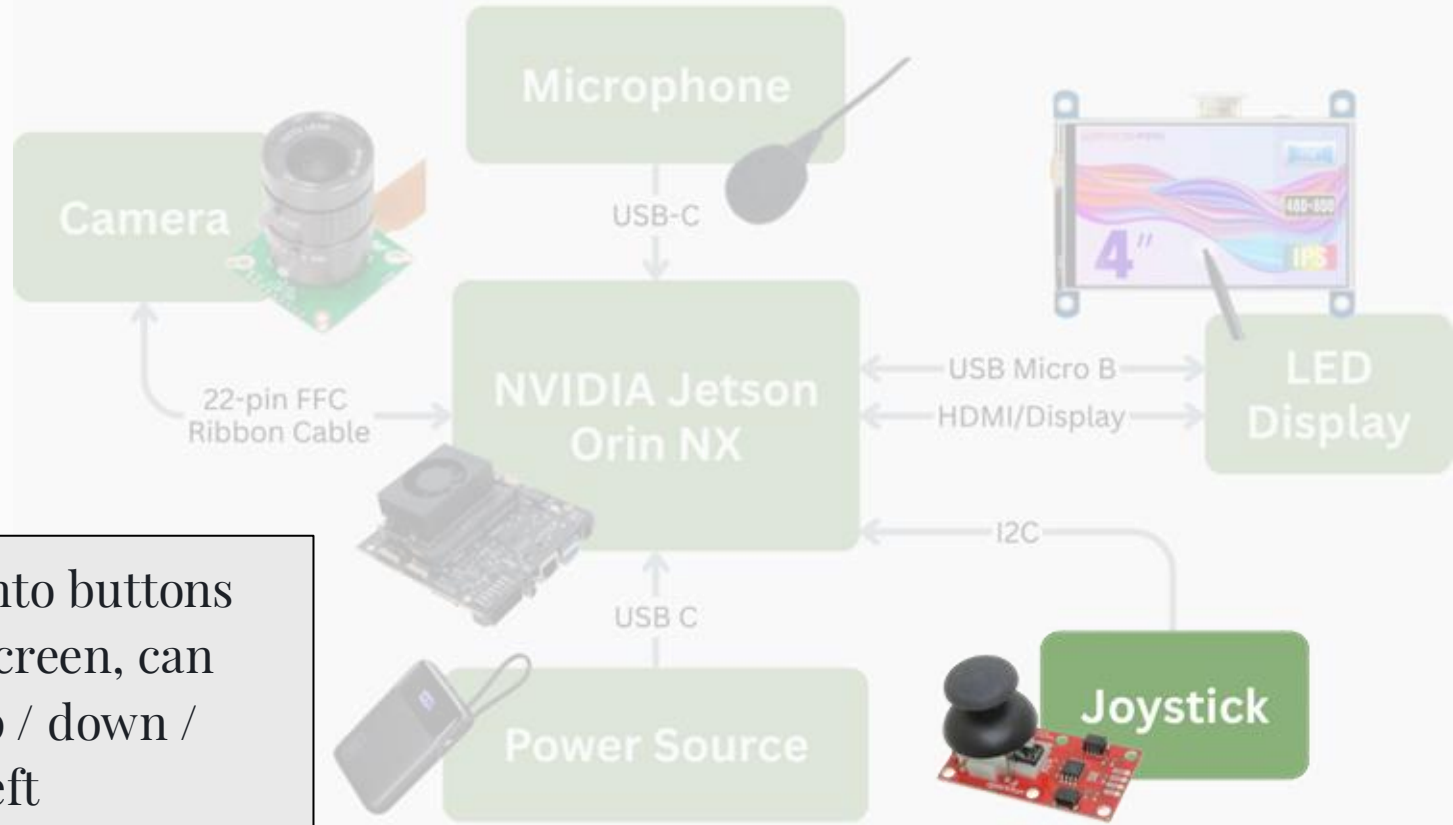
Capture input for
voice transcription
feature

Hardware Overview



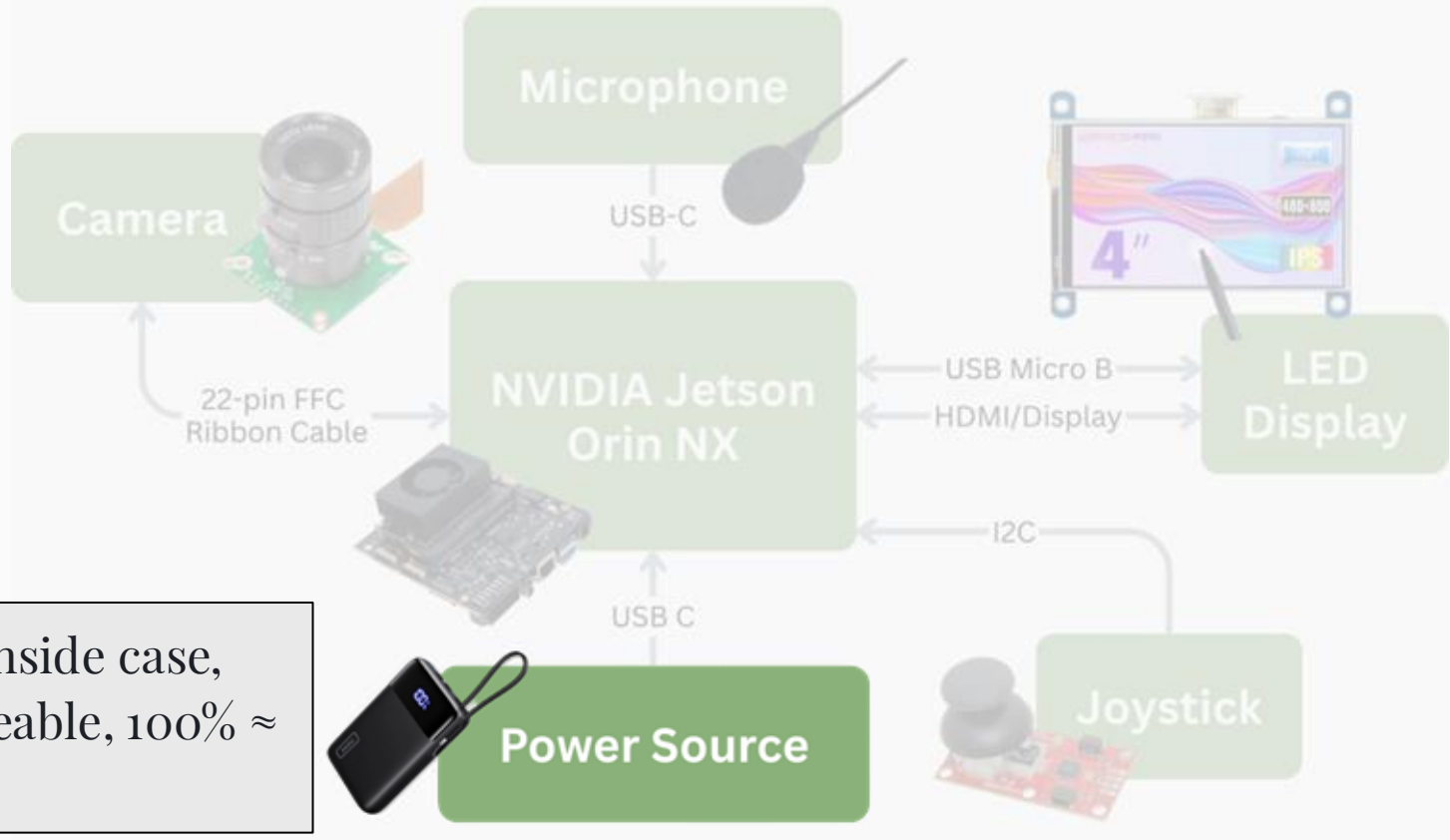
Real-time
classification results,
volume estimates,
and transcriptions

Hardware Overview



Locks onto buttons
on the screen, can
move up / down /
right / left

Hardware Overview



Stored inside case,
rechargeable, 100% $\approx$
6 hours

Rock Classification

6:19 PM Tuesday, May 26, 2026 28%

ANORTHOSITE



Confidence: 69% Volume = 641.6 cm³
Weight: 1.60-1.92 kg

Brightness: high (61%)
Plagioclase-rich; minimal dark minerals.

Crystal Fabric: equigranular (94%)
Uniform grain sizes; stable plutonic cooling.

Mafic Content Hint: low (92%)
Few dark minerals; mostly plagioclase.

Surface Character: weathered (95%)
Alteration or microfracturing visible.

Alternatively:

BRECCIA conf: 20%	BASALT conf: 6%
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Rock Classification

- **Model Input:** Image of rock from camera
- **Model Output:**
 - Primary class label
 - Feature labels
 - Confidence scores

6:19 PM Tuesday, May 26, 2026 28%

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-----------------------------	---------------------------

Rock Classification Model – Data

➤ Dataset:

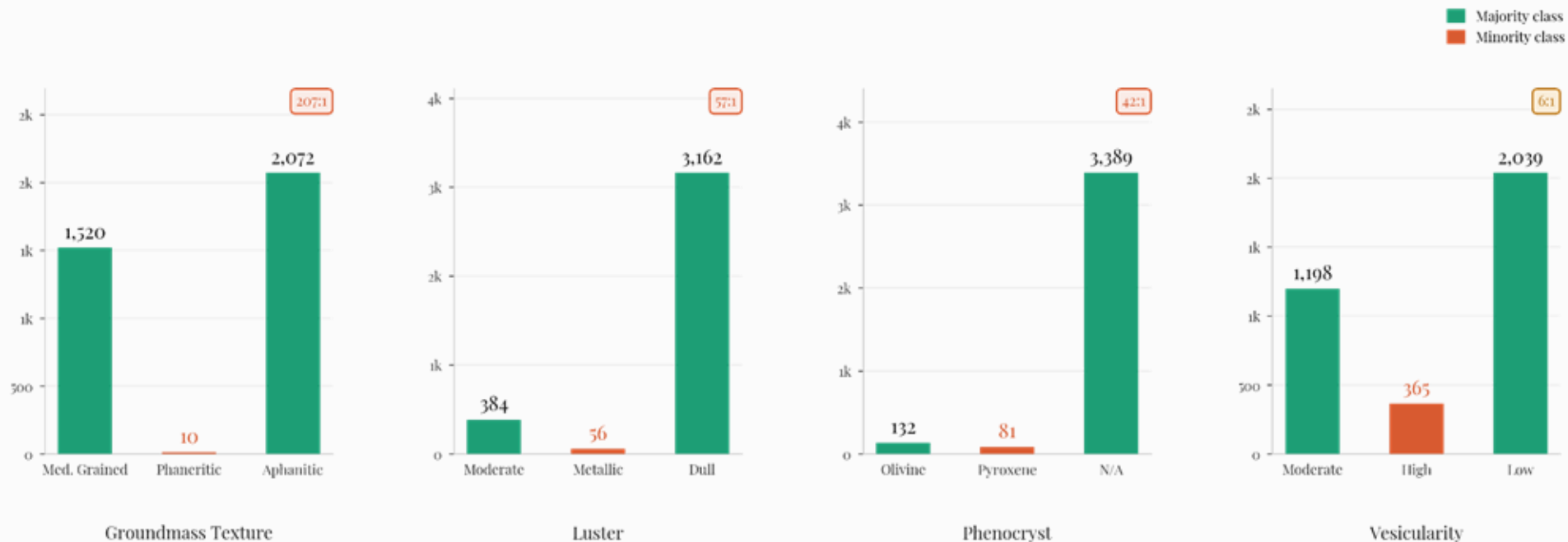
- Lunar + earth rock images collected from 10 sources
- Features analyzed and auto-labeled with Claude

➤ Challenge #1: Class imbalance

Source	Basalt	Breccia	Anorthosite
JSC	2800	1854	34
LPI	0	0	90
Kaggle (4)	1000	15	61
Smithsonian	200	17	2
Flickr	164	74	374
Astromaterials	14	27	3
Manual	26	0	10
Total	4204	1987	574

Rock Classification Model – Data

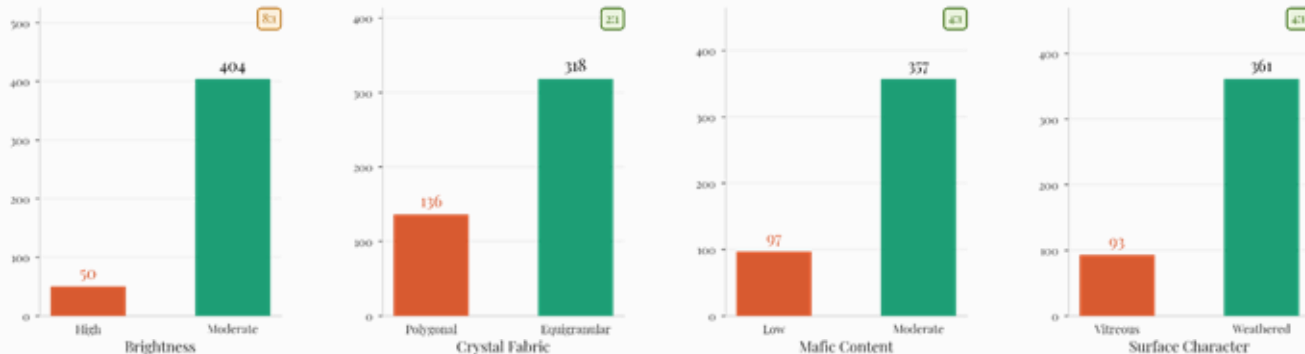
➤ Images per **Basalt** feature classifications



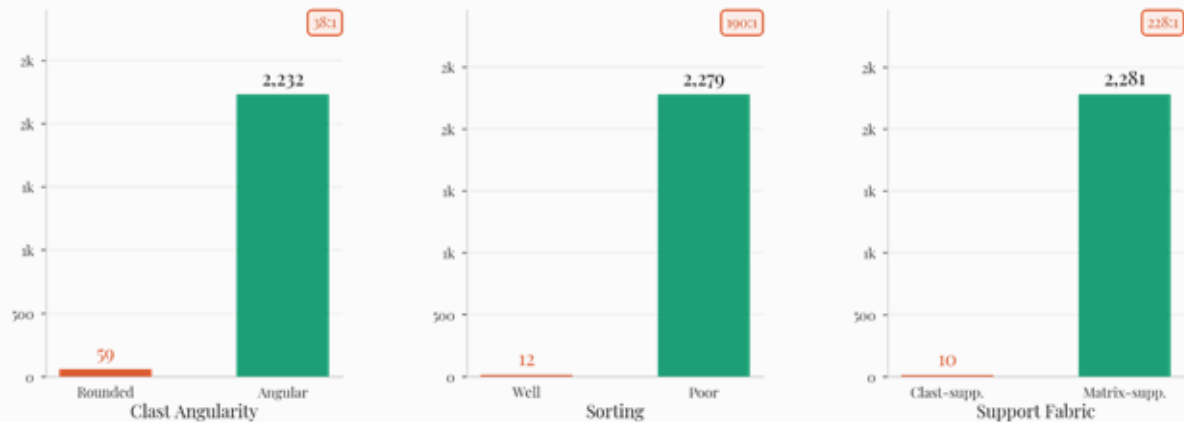
Rock Classification Model – Data

Majority class Minority class

- Images per **Anorthosite** feature classifications



- Images per **Breccia** feature classifications

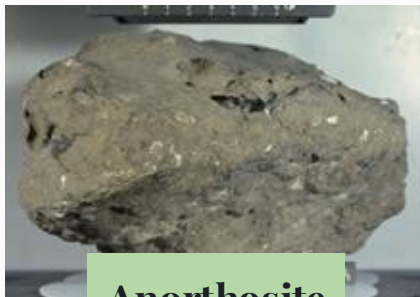


Rock Classification Model

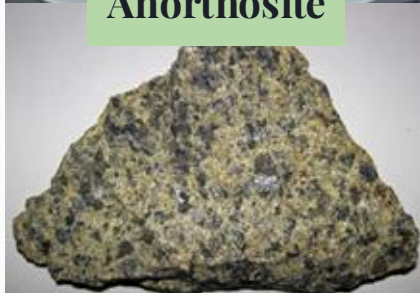
- **Challenge #2:** Inter-class similarities, intra-class variances



Basalt



Anorthosite



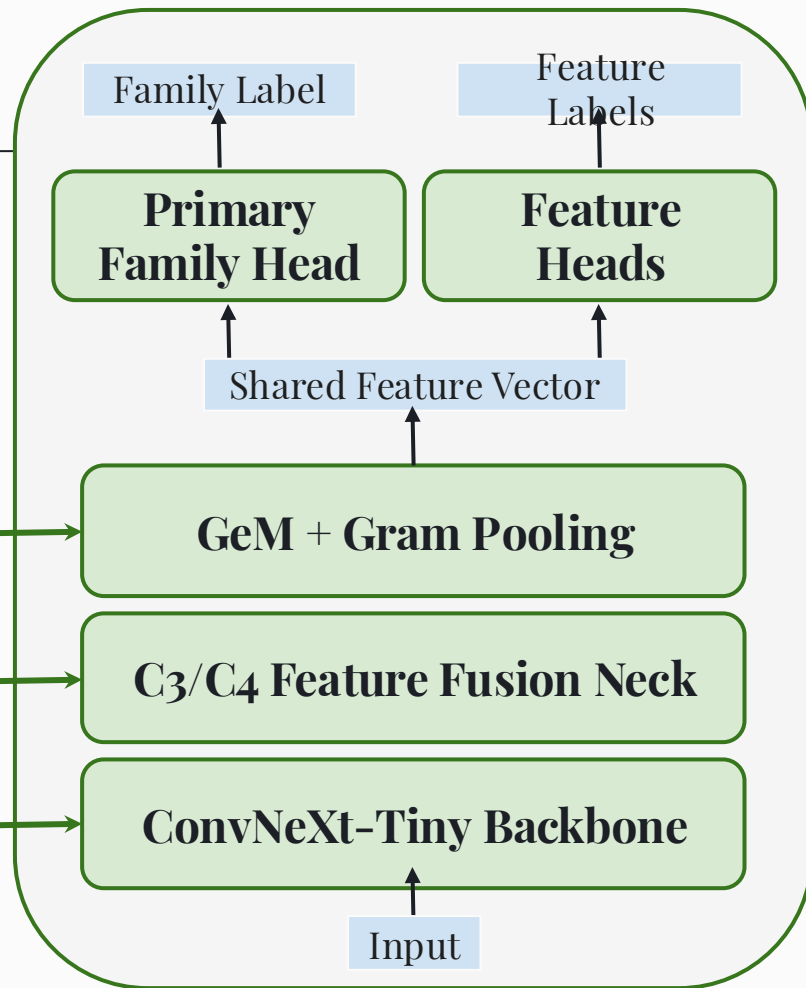
Breccia



Rock Classification Model

➤ Model Architecture:

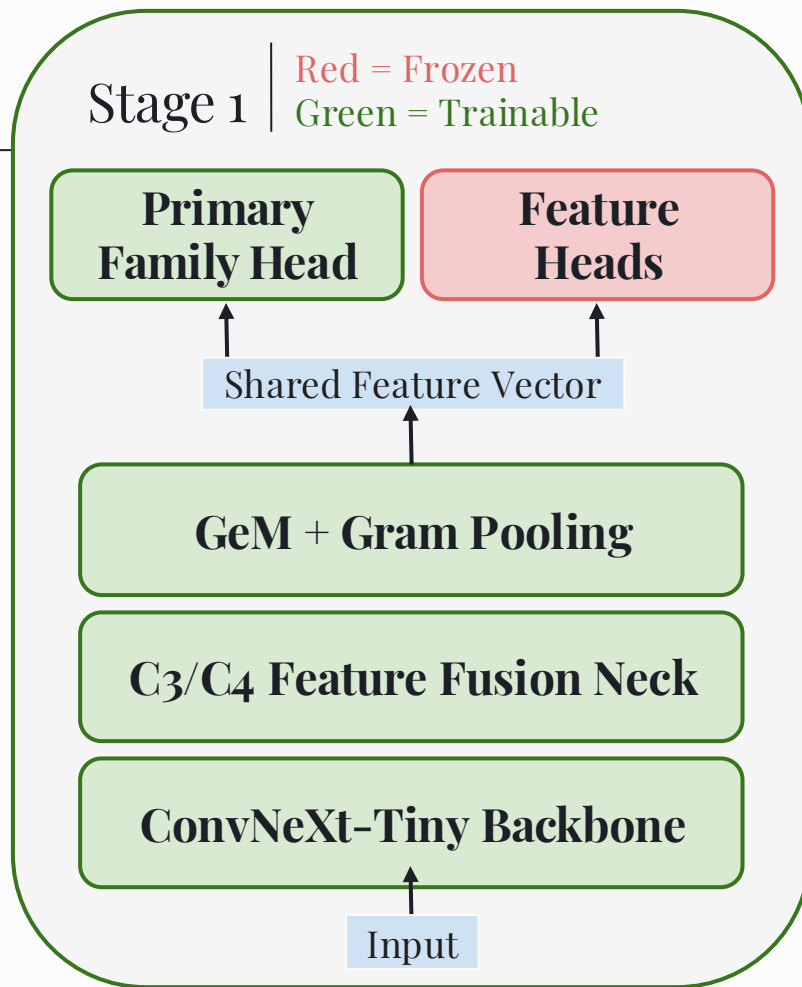
- GeM captures distinct local features, Gram captures overall texture patterns
- Combines mid-level texture features with higher-level semantic features
- Extracts general visual features



Rock Classification Model

➤ Training Approach:

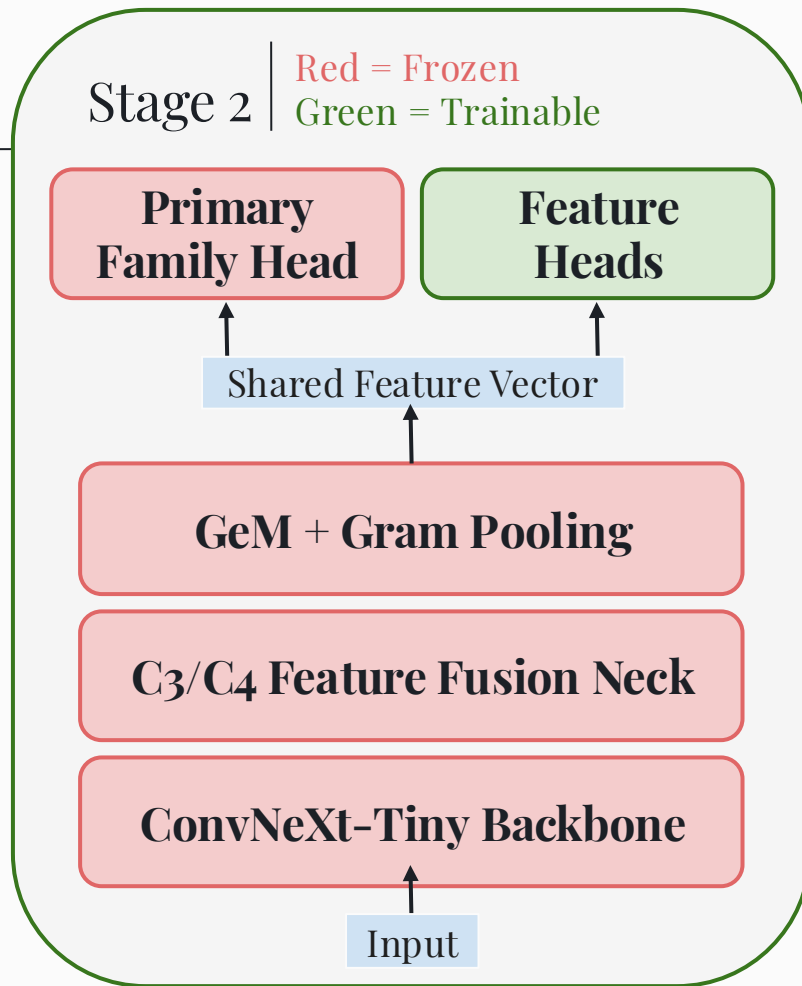
1. Weighted cross-entropy and balanced accuracy to handle class imbalance
2. Phased fine-tuning for stable training
3. 3-staged training



Rock Classification Model

➤ Training Approach:

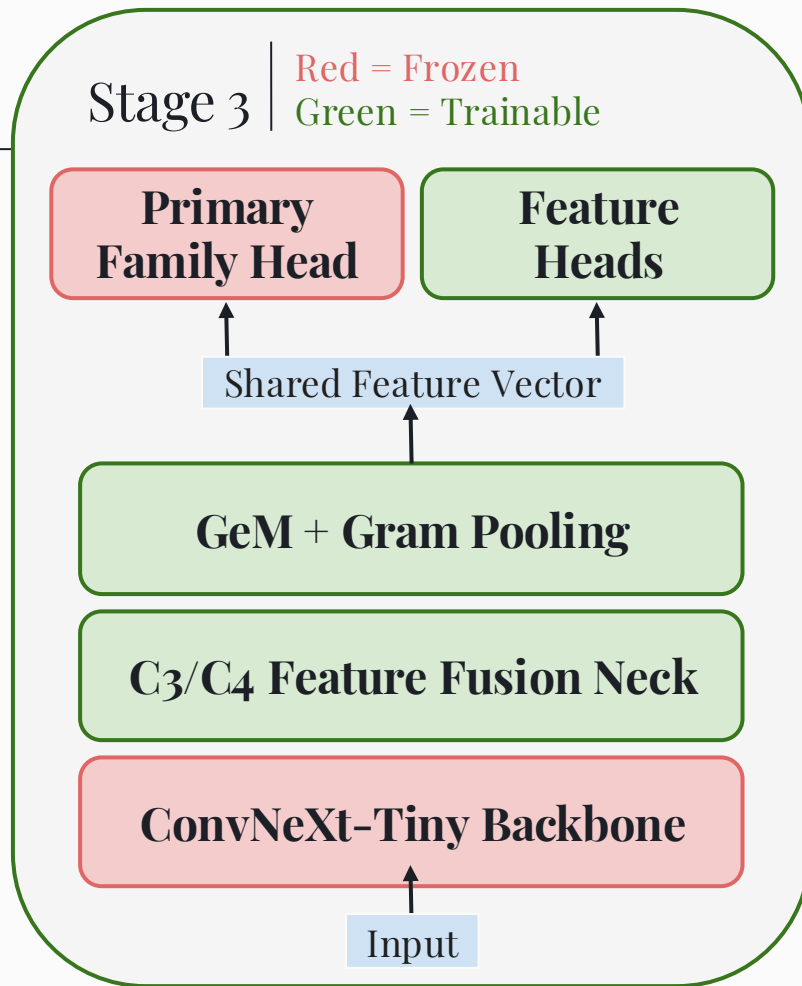
1. Weighted cross-entropy and balanced accuracy to handle class imbalance
2. Phased fine-tuning for stable training
3. 3-staged training



Rock Classification Model

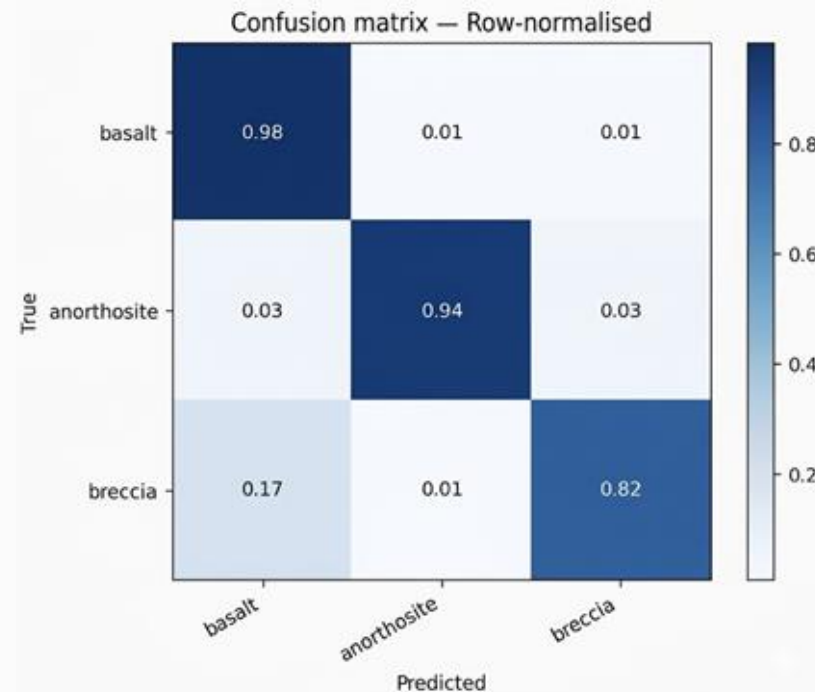
➤ Training Approach:

1. Weighted cross-entropy and balanced accuracy to handle class imbalance
2. Phased fine-tuning for stable training
3. 3-staged training



Rock Classification Model

- **Primary rock family classifier:**
 - 91% accuracy
- **Family-specific feature labels:**
 - 86% accuracy
- **Future improvements:**
 - Expand dataset for model to be able to classify more rock families + features



Volume Calculation

6:19 PM Tuesday, May 26, 2026 28%

ANORTHOSITE



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Surface Character: weathered (95%)
Alteration or microfracturing visible.

Alternatively:

BRECCIA conf: 20% **BASALT** conf: 6%

Volume Calculation

- **Purpose:** Estimate rock dimensions, volume, and mass from two orthogonal images using AprilTag scaling and SAM segmentation.
- **Inputs:**
 - Top view image, side view image, AprilTag
- **Outputs:**
 - L, H, W
 - Volume (cm³)
 - Mass (g)



Top View



Side View



$L \times W \times H$ (cm): $X \times Y \times Z$

Volume (cm³): A

Mass range (kg): B to C

Volume Calculation

➤ Key Steps:

- Detect AprilTag
- Convert pixels to centimeters
- Segment rock using SAM
- Remove AprilTag from mask
- Extract clean rock



Volume Calculation

➤ Geometry:

- Footprint Area from top mask
- Length & Width from minimum-area bounding rectangle
- Height from side-view extent



➤ Result:

- Length (cm)
- Width (cm)
- Height (cm)



Volume Calculation

➤ Shape Analysis:

- Circularity
- Solidity
- Shape Factor (0.5-0.85)

➤ Volume Models:

- Ellipsoid
- Area-Based
- Adaptive Selection

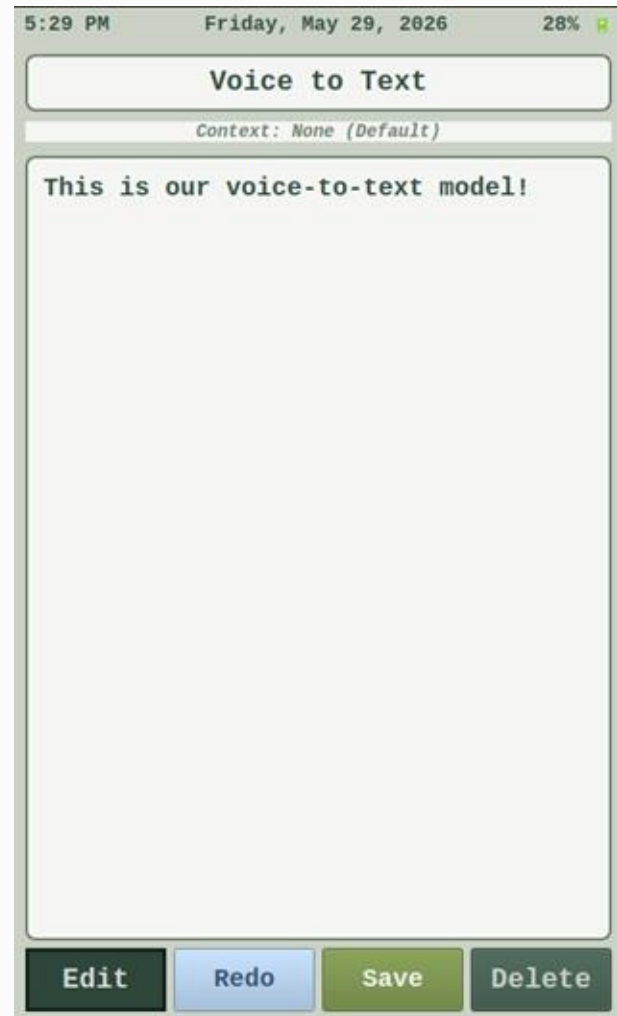


$L \times W \times H$ (cm): $18.16 \times 12.80 \times 17.79$

Volume (cm³): 2165.3

Mass range (kg): 5.413 to 6.496

Voice Transcriptions



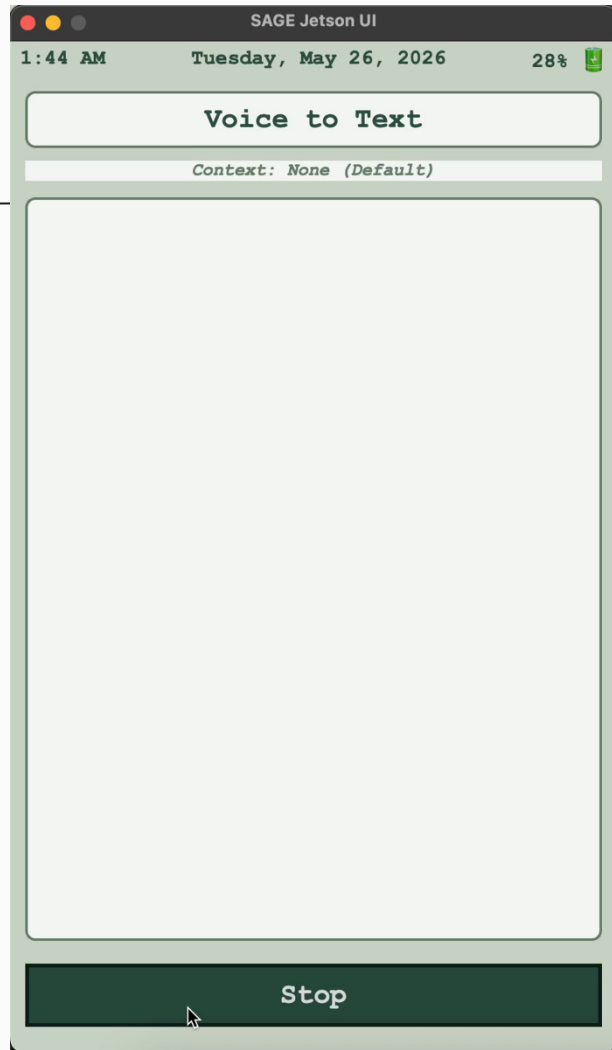
Voice Transcription

➤ Overview

- LAV Microphone
- NeMo ASR Model
 - Customized and fine-tuned with additional layers

➤ Features

- Transcribes speech in real-time
 - Rolling window
- Clean-up at the end of recording
 - Visual context + spelling + phonetics
- Final Transcript
 - LLM runs capitalization + punctuation



Voice Transcription – Fine Tuning

➤ Data Collection

- ~10 hours of geology lectures/podcasts

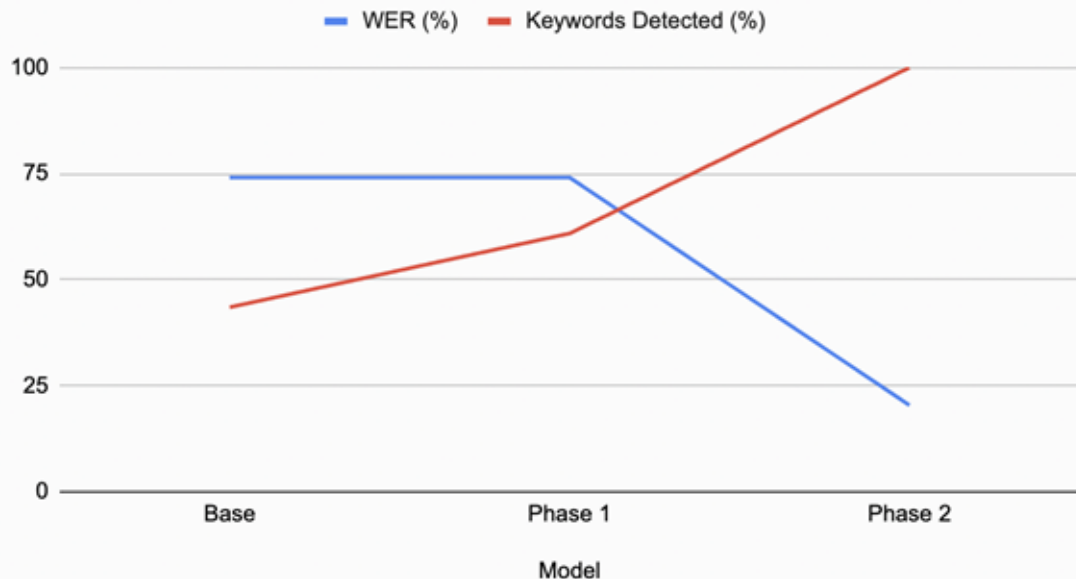
➤ Data Preparation

- Segmentation
- Filter out low-quality segments

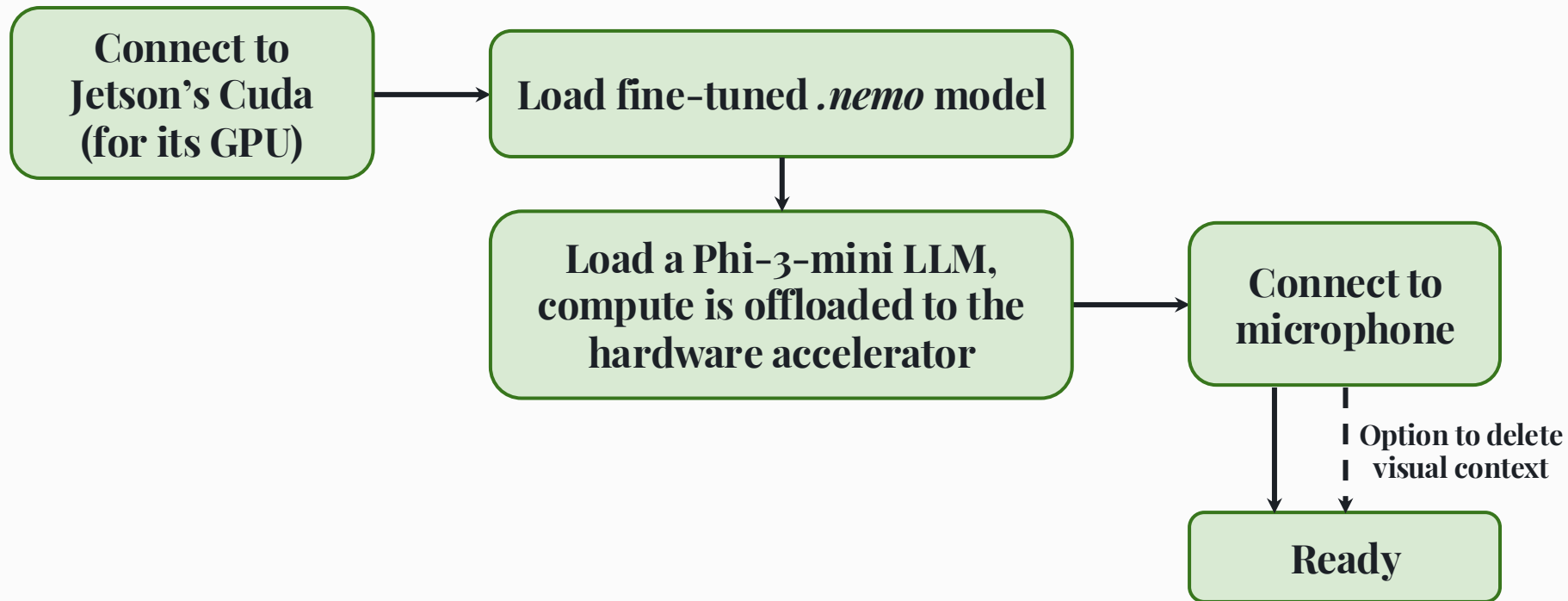
➤ Fine Tuning

- Phase 1 – only decoder
- Phase 2 – encoder + decoder

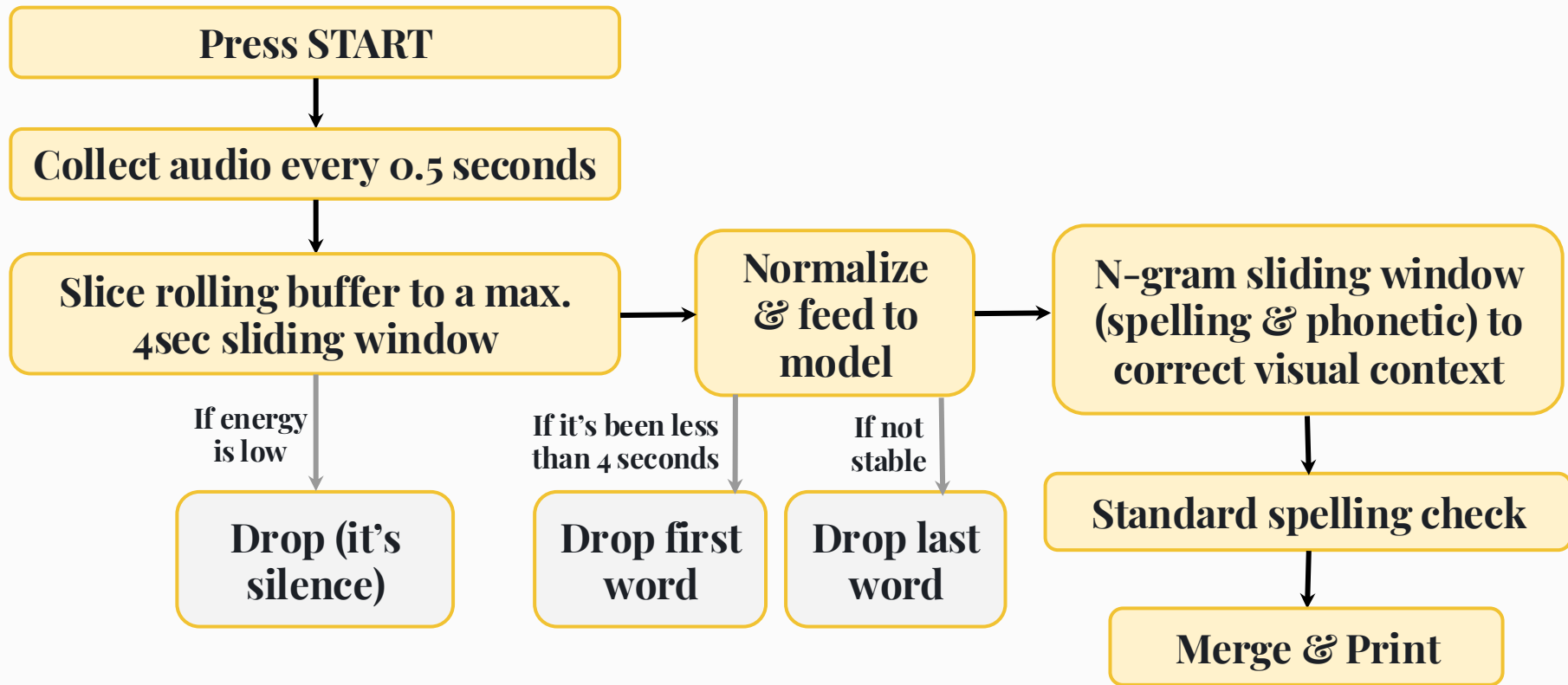
WER (%) and Keywords Detected (%)



Voice Transcription - Architecture



Voice Transcription - Architecture



Voice Transcription - Architecture

Press STOP

↓ Add last word

**Run massive ASR
on full audio**

**Identify tokens with
< 85% confidence**

**Extract top 4 guesses and
put them in a file**

**N-gram sliding window
& spell checker**

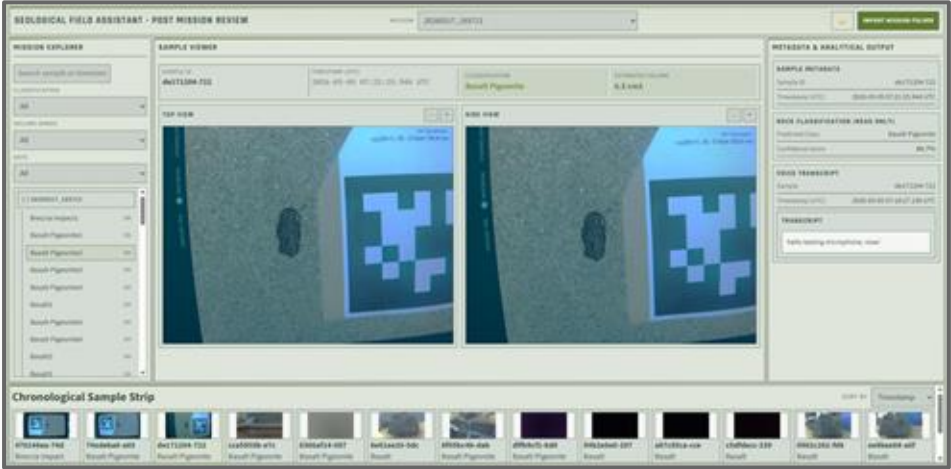
**Phi-3-mini polishes
capitalization/punctuation**

Print



AI summary

Ground User Interface



Ground UI Overview

GEOLOGICAL FIELD ASSISTANT - POST MISSION REVIEW

MISSION20260517_185713

IMPORT MISSION FOLDER

MISSION EXPLORER

Search sample or timestamp

CLASSIFICATION

All

VOLUME RANGE

All

DATE

All

20260517_185713

Breccia Impact1OK

Basalt Pigeonite1OK

Basalt Pigeonite2OK

Basalt Pigeonite3OK

Basalt Pigeonite4OK

Basalt1OK

Basalt Pigeonite5OK

Basalt Pigeonite6OK

Basalt2OK

Basalt3OK

SAMPLE VIEWER

SAMPLE ID

de171204-722

Timestamp (UTC)

2026-03-05 07:21:25.944 UTC

CLASSIFICATION

Basalt Pigeonite

ESTIMATED VOLUME

6.5 cm3

TOP VIEW



SIDE VIEW



METADATA & ANALYTICAL OUTPUT

SAMPLE METADATA

Sample IDde171204-722

Timestamp (UTC)2026-03-05 07:21:25.944 UTC

ROCK CLASSIFICATION (READ ONLY)

Predicted ClassBasalt Pigeonite

Confidence Score60.7%

VOICE TRANSCRIPT

Samplede171204-722

Timestamp (UTC)2026-03-05 07:18:27.236 UTC

TRANSCRIPT

hello testing microphone, now!

Chronological Sample Strip

470148ea-74dBreccia Impact

74ede8a0-a65Basalt Pigeonite

de171204-722Basalt Pigeonite

cca5950b-e7cBasalt Pigeonite

6366af14-087Basalt Pigeonite

8e61ee20-5dcBasalt

8f05bc4b-dabBasalt Pigeonite

dfb9cf1-6d0Basalt Pigeonite

94b2e6e0-207Basalt

a87c85ca-cceBasalt

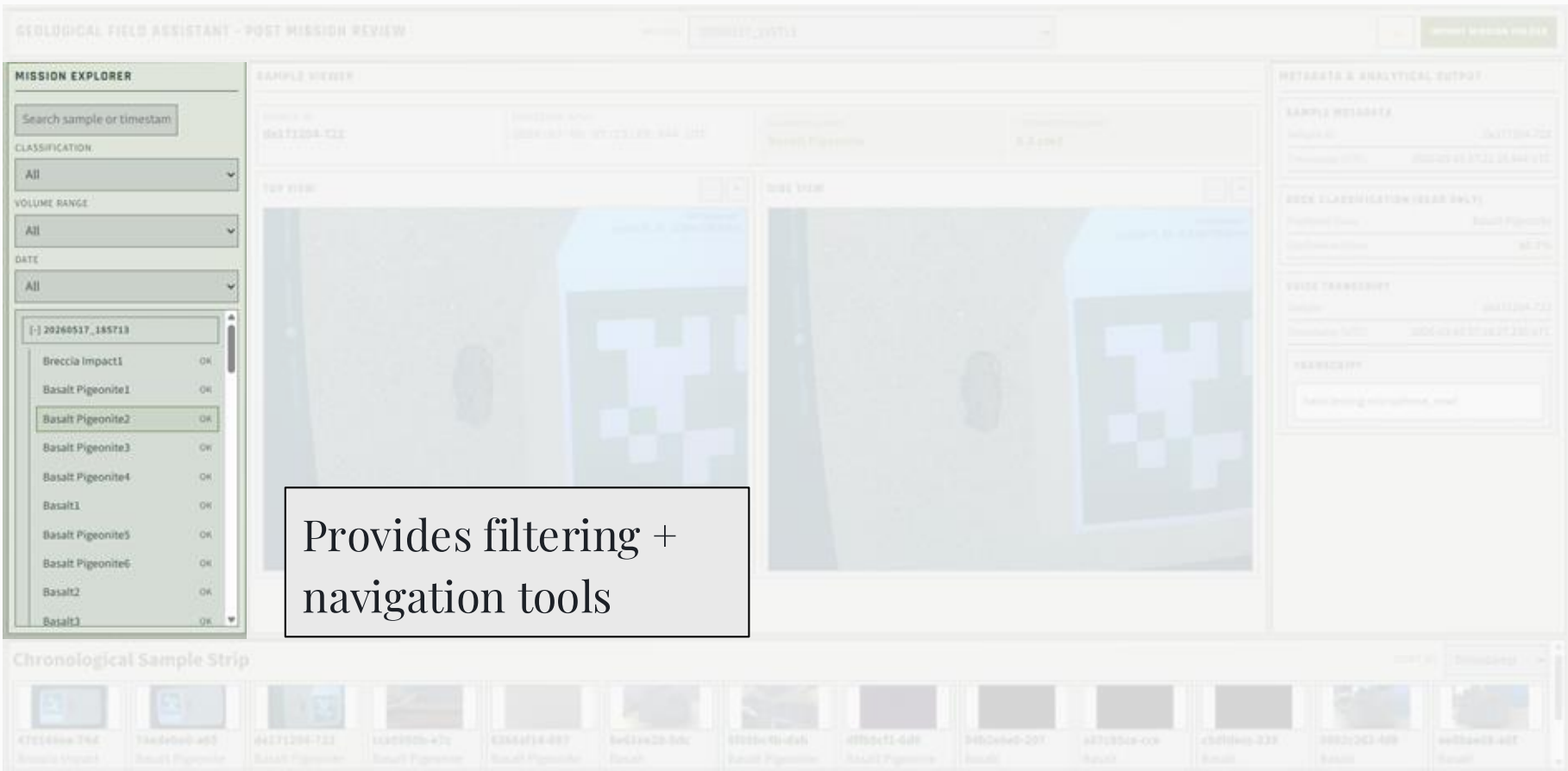
c5dfdecc-339Basalt

0982c262-fd8Basalt

ee8bae68-a6fBasalt

SORT BY

Timestamp





METADATA & ANALYTICAL OUTPUT

SAMPLE METADATA

Sample ID	de171204-722
Timestamp (UTC)	2026-03-05 07:21:25.944 UTC

ROCK CLASSIFICATION (READ ONLY)

Predicted Class	Basalt Pigeonite
Confidence Score	60.7%

VOICE TRANSCRIPT

Sample	de171204-722
Timestamp (UTC)	2026-03-05 07:18:27.236 UTC

TRANSCRIPT

hello testing microphone, now!

Presents detailed information and metadata

GEOLOGICAL FIELD ASSISTANT - POST MISSION REVIEW

MISSION EXPLORER

MISSION NAME: de272204-722

MISSION TYPE: Basalt Pigeonite

MISSION STATUS: Active

MISSION DATE: 2024-05-05 08:10:10Z

MISSION LOCATION: 9.3 10.8

SAMPLE VIEWER

Sample ID: de272204-722

Sample Name: Basalt Pigeonite

Sample Type: Basalt Pigeonite

Sample Status: Active

Sample Date: 2024-05-05 08:10:10Z

Sample Location: 9.3 10.8

METADATA & ANALYTICAL OUTPUT

SAMPLE METADATA

Sample ID: de272204-722

Sample Name: Basalt Pigeonite

Sample Type: Basalt Pigeonite

Sample Status: Active

Sample Date: 2024-05-05 08:10:10Z

Sample Location: 9.3 10.8

ROCK CLASSIFICATION (BRD UNIT)

Rock Classification: Basalt Pigeonite

Rock Classification: Basalt Pigeonite

ROCK DESCRIPTION

Rock Description: Basalt Pigeonite

Rock Description: Basalt Pigeonite

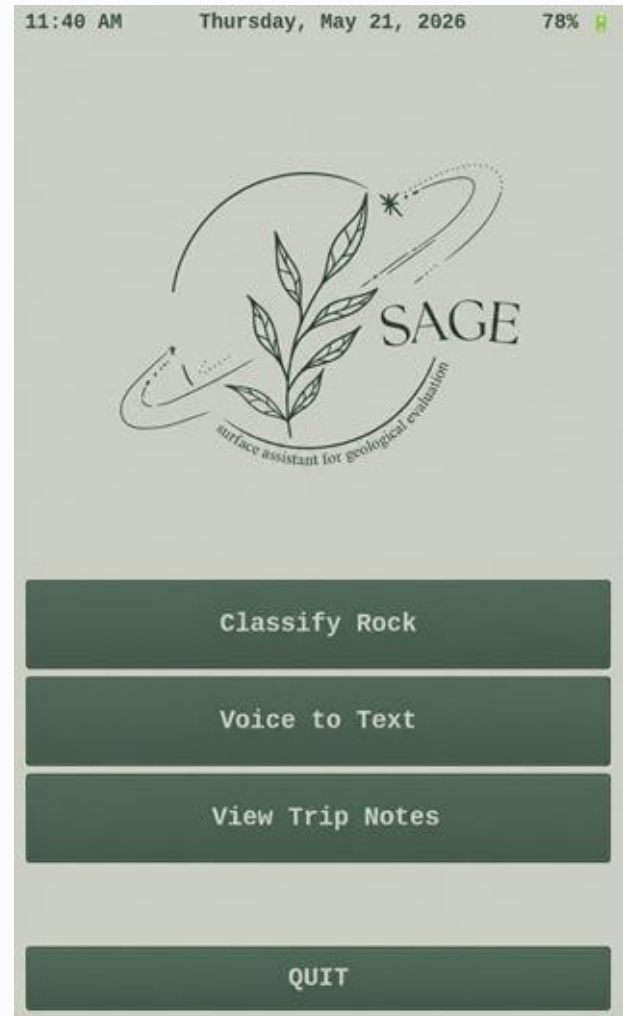
Timeline view of collected samples

Chronological Sample Strip

SORT BY: Timestamp

												
470148ea-74d Breccia Impact	74edeba0-a65 Basalt Pigeonite	de171204-722 Basalt Pigeonite	cca5950b-e7c Basalt Pigeonite	6366af14-087 Basalt Pigeonite	8e61ee20-5dc Basalt	8f05bc4b-dab Basalt Pigeonite	dffb9cf1-6d0 Basalt Pigeonite	94b2e6e0-207 Basalt	a87c85ca-cce Basalt	c5dfdecc-339 Basalt	0982c262-fd8 Basalt	ee8bae68-a6f Basalt

Display & Integration



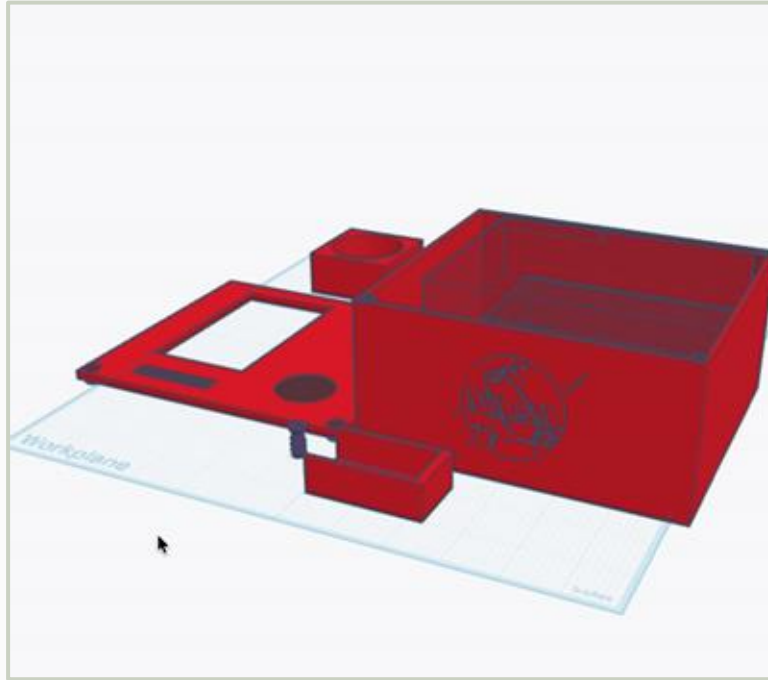
Putting It All Together...

➤ User Interaction

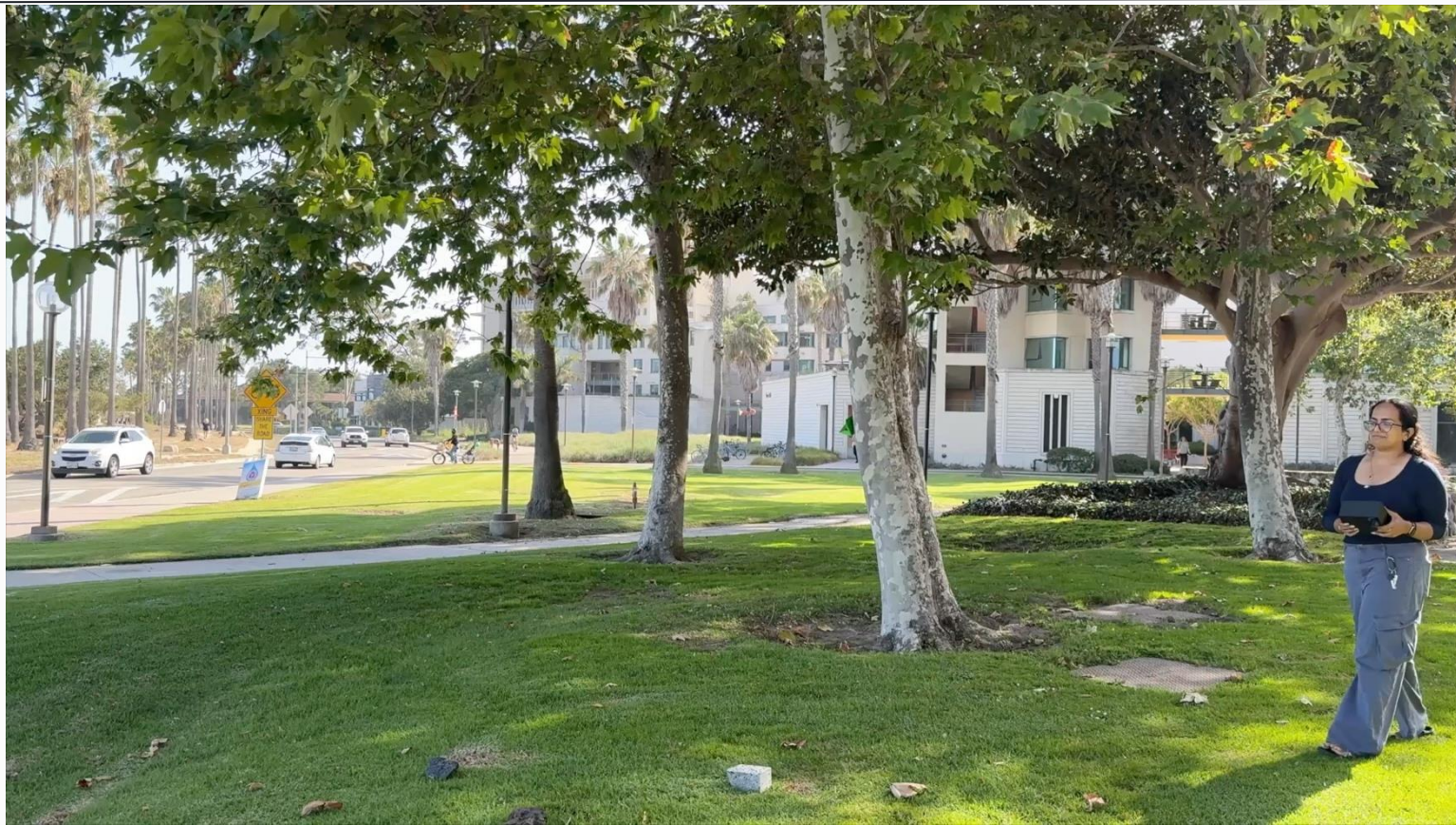
- Python + PySide GUI
- Joystick Module

➤ CAD Case

- Tinkercad



End-to-End Demo



Thank you!

Special thanks to Jessica Marquez & John Karasinski
at NASA, and Professor Isukapalli and Kriteen
Shrestha for the guidance and support!

