INSTITUTO DE PESQUISAS TECNOLÓGICAS

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Characterizing geological-geotechnical substrate layers through sar tomography: applications and challenges

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INSTITUTO DE PESQUISAS TECNOLÓGICAS

CHARACTERIZING GEOLOGICAL–GEOTECHNICAL SUBSTRATE LAYERS THROUGH SAR TOMOGRAPHY: APPLICATIONS AND CHALLENGES

Carlos Tadeu de Carvalho Gamba

SÃO PAULO
GOVERNO DO ESTADO

THE SAR TOMOGRAPHY TECHNOLOGY

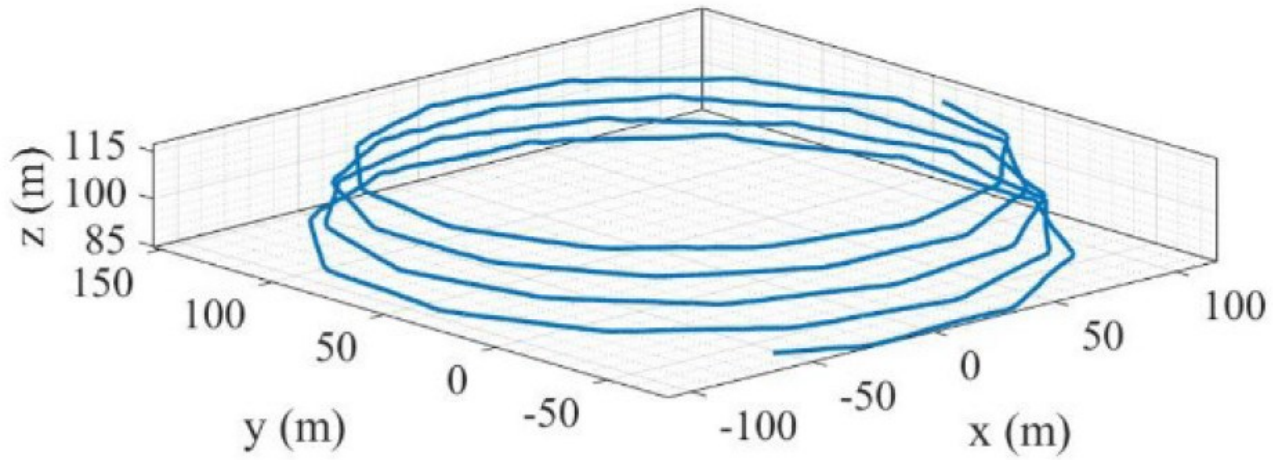
- SAR Tomography is a technique that **provides three-dimensional information about materials located beneath the surface**.

- It can be used to **identify different soil layers**, **fresh** or **weathered rock layers**, and even **buried objects**.

- It works **similarly to Ground Penetrating Radar** (GPR), but has the difference and advantage of being operated from an airborne platform (DRONE), allowing **data collection even over irregular terrain or areas covered by vegetation**.

HOW SAR TOMOGRAPHY WORKS

- SAR Tomography uses an **airborne platform** (DRONE) to simulate a traditional tomography process.



- The UAV-SAR performs a **helical descending flight along a conical orbit to acquire subsurface information**.

THE SAR TOMOGRAPHY SYSTEM

- **Explorer RD350** – A multiband drone-borne SAR system (UAV-SAR)

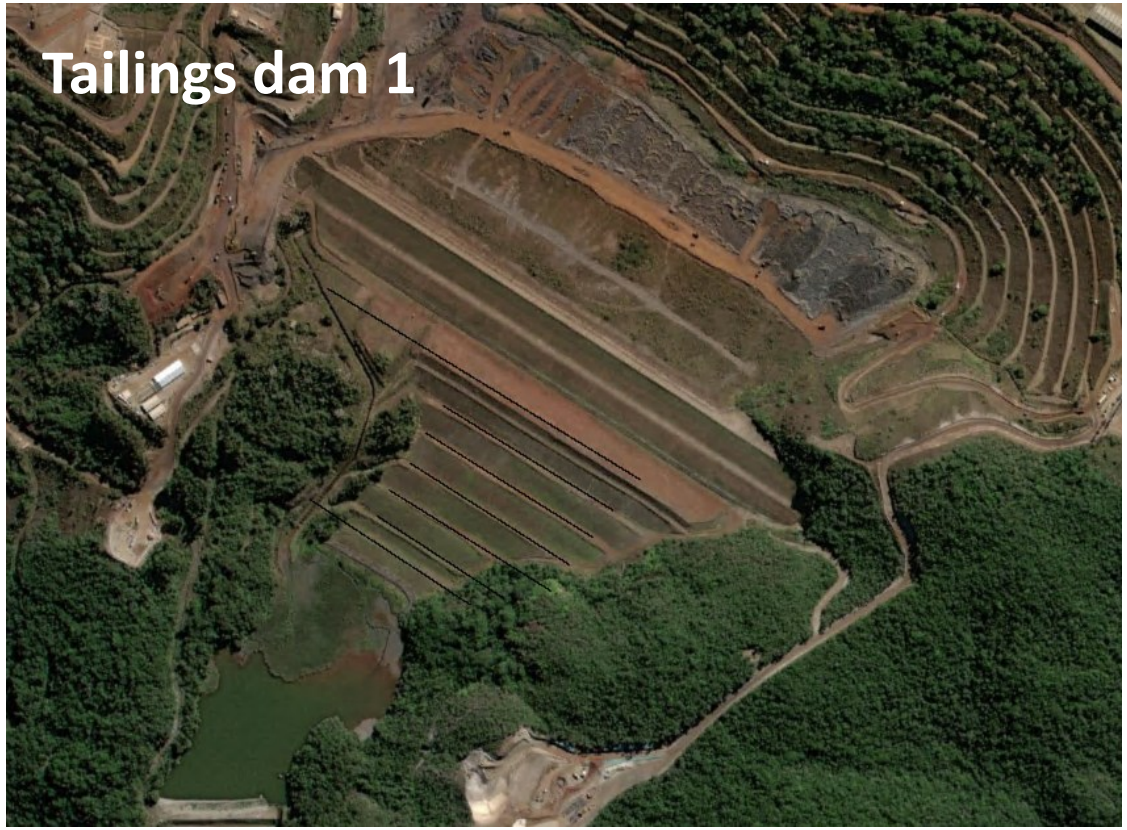
Radar Parameters	P band
Polarization	HH
Wavelength (cm)	70.5
Bandwidth (MHz)	50
Azimuth aperture (°)	55.9
Elevation aperture (°)	69.3
Azimuth resolution (cm)	30.0
Range resolution (m)	4.0

RESEARCH GOALS AND CHALLENGES

- Identify in the subsurface, using SAR tomography, the more competent rock layers (foundation soil or bedrock level);
- Classify the spectral behavior of different rock layers (fresh or weathered) in the subsurface;
- Determine, through the use of SAR tomography, the depth bedrock level;
- Generate surface models of the bedrock layer

EXAMPLES

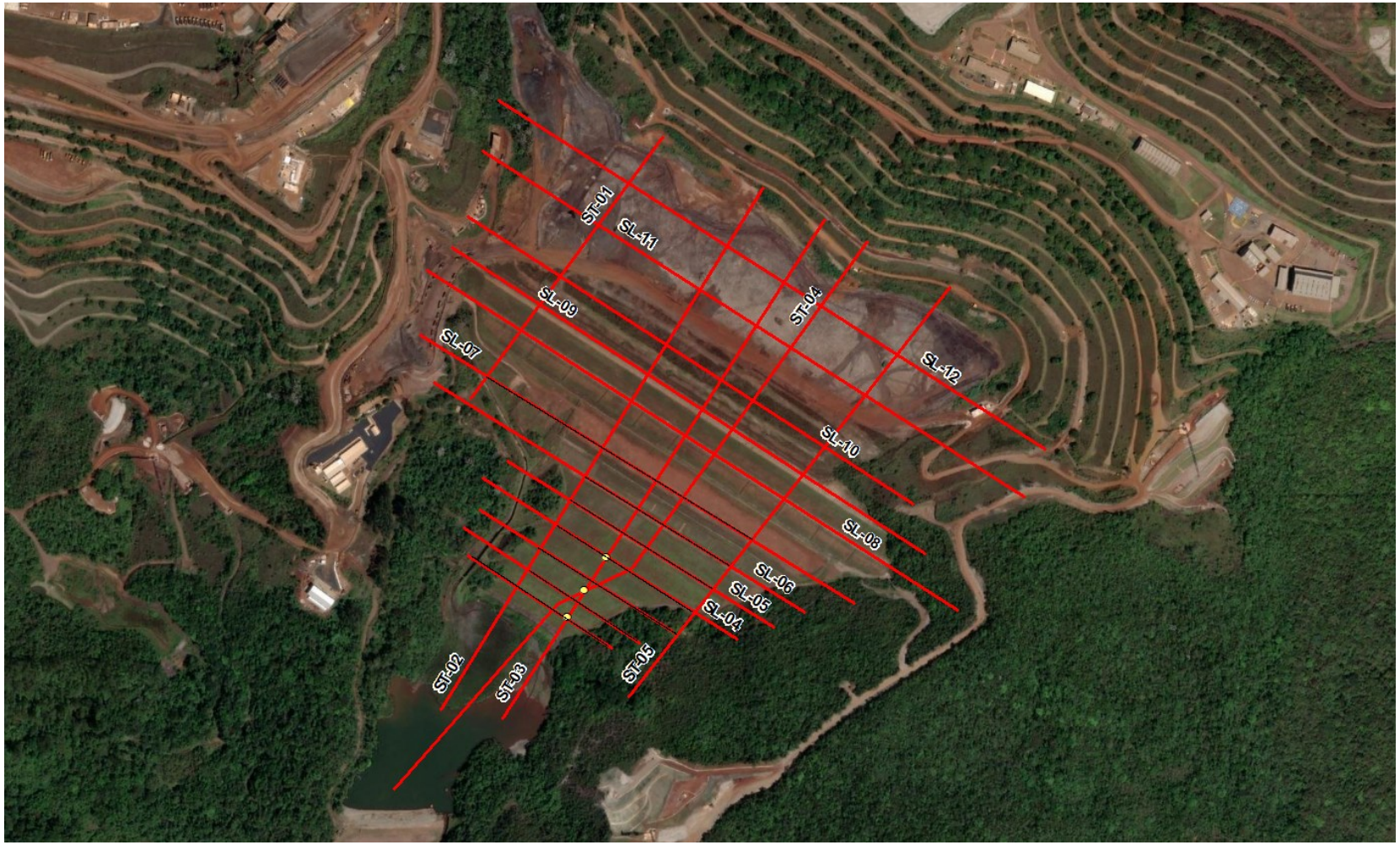
- 2 sites and 4 different approaches



TAILINGS DAM 1

- **Apply SAR Tomography to identify subsurface layers** in a mining tailings dam area;
- **Identify the dolomitic layer** using **SAR tomography** and geological profiles;
- **Understand** the **SAR Tomography reflection behavior** with different rock layers;
- **Compare** the results with geological profiles.

TAILINGS DAM 1



TAILINGS DAM 2

- **Apply SAR Tomography to identify subsurface layers** in a mining tailings dam area.

- Focusing on **three steps**:

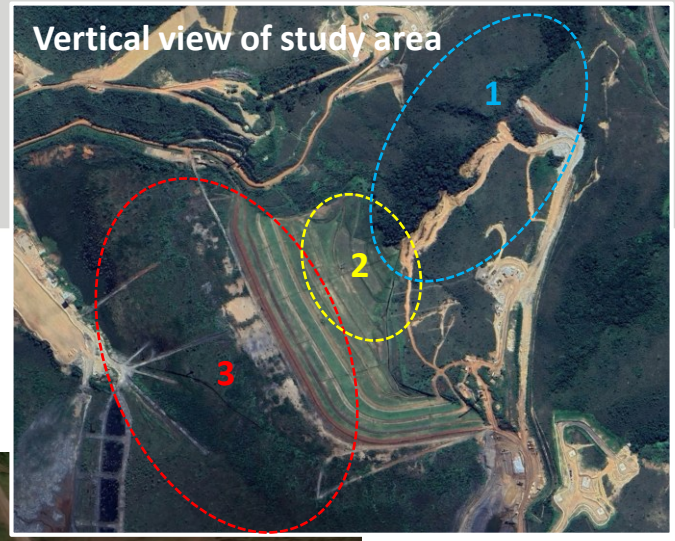
  1. **Map the most competent soil layer** (foundation soil), immediately below the alluvium-colluvium on the **downstream** side of the dam;

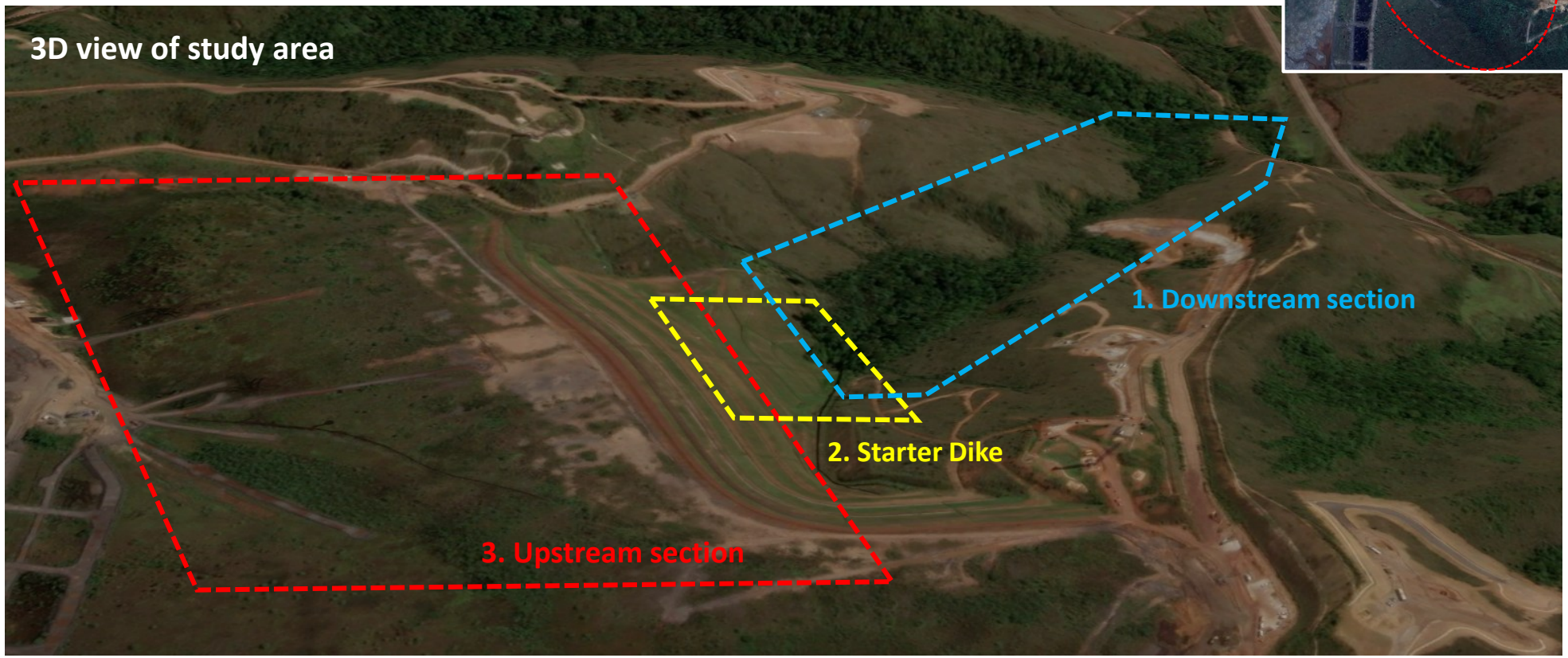
  2. **Identify and map the most competent soil layer** (foundation soil) of the **dam´s starter dike**;

  3. **Identify and map the bedrock layer** on the upstream of the dam.

TAILINGS DAM 2

- 3 different approaches at the same area



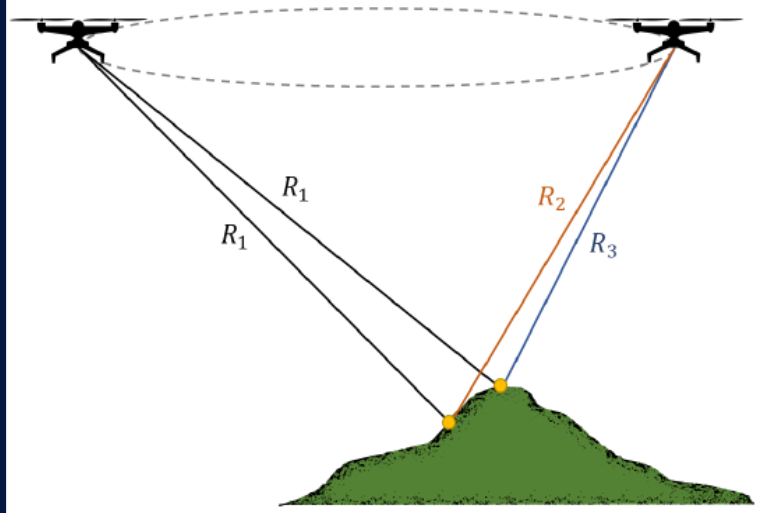


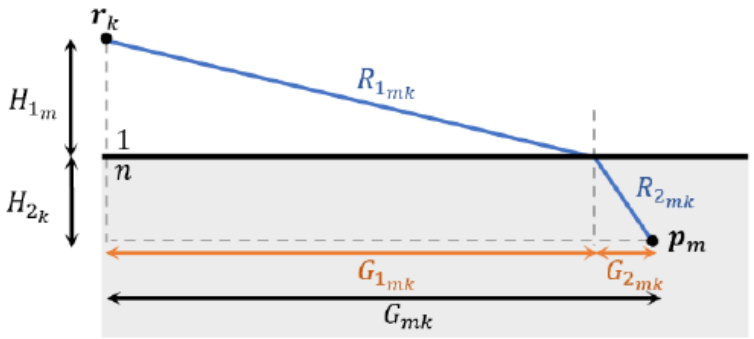
SAR TOMOGRAPHY STRATEGY

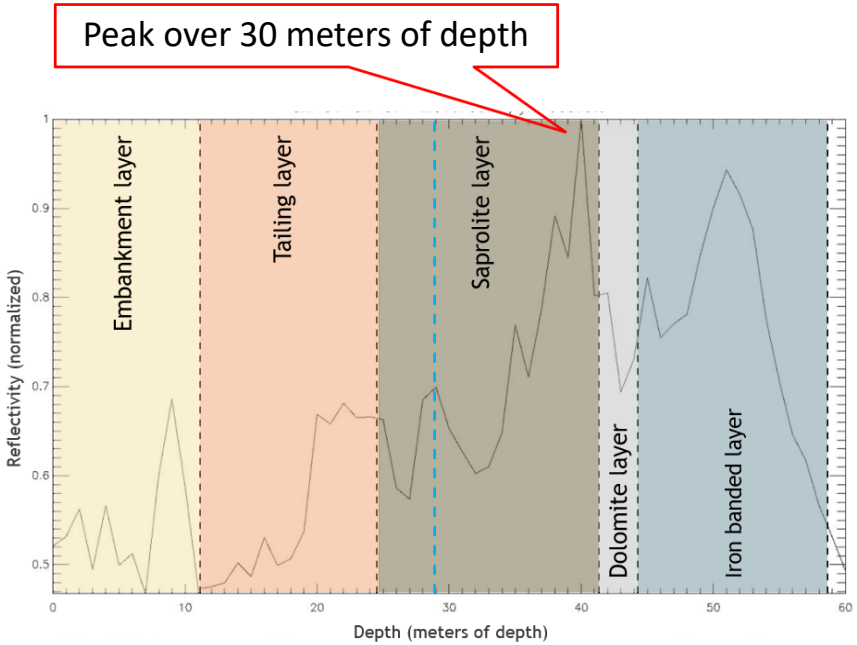
- **Step 1**: Mapping the subsurface with Airborne SAR;
- **Step 2**: Generate sample points in processed SAR data, indicating the signal behavior along depth;
- **Step 3**: Compare the results of the SAR surveys with geotechnical investigation data obtained from borehole drilling or other informations;
- **Step 4**: Identify the foundation soil or bedrock level at the sample points and extrapolate the information across the entire mapped area.

SAR TOMOGRAPHY PROCESSING STRATEGY

Field reference data were **used to adjust** the signal processing.





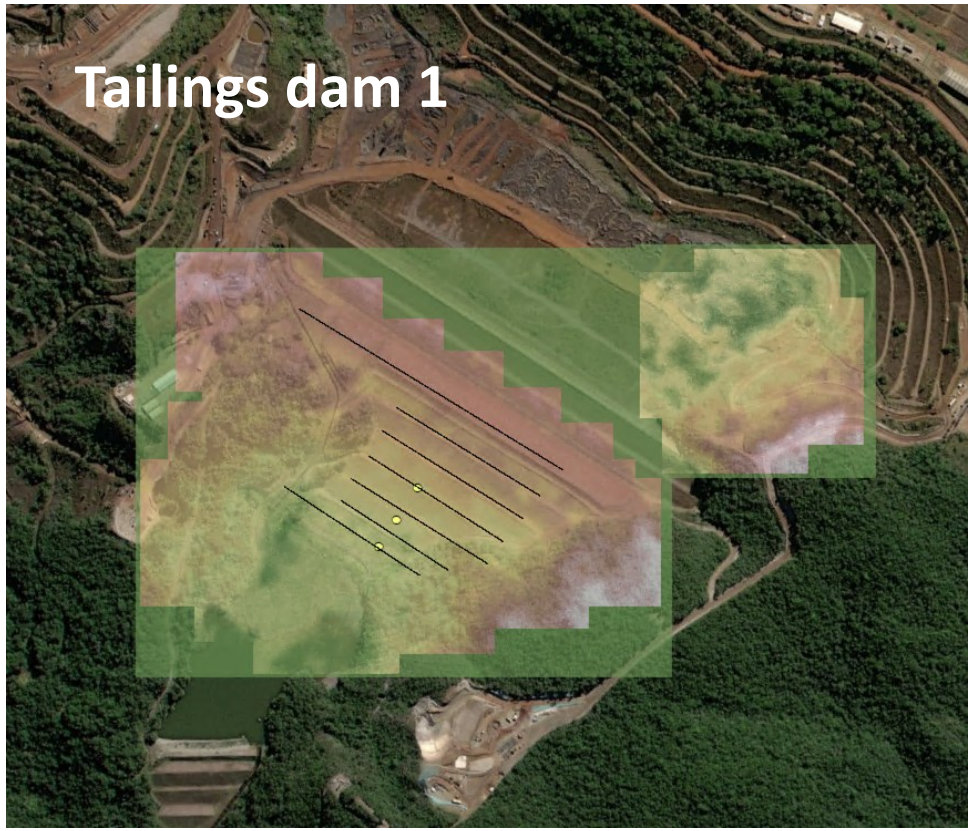


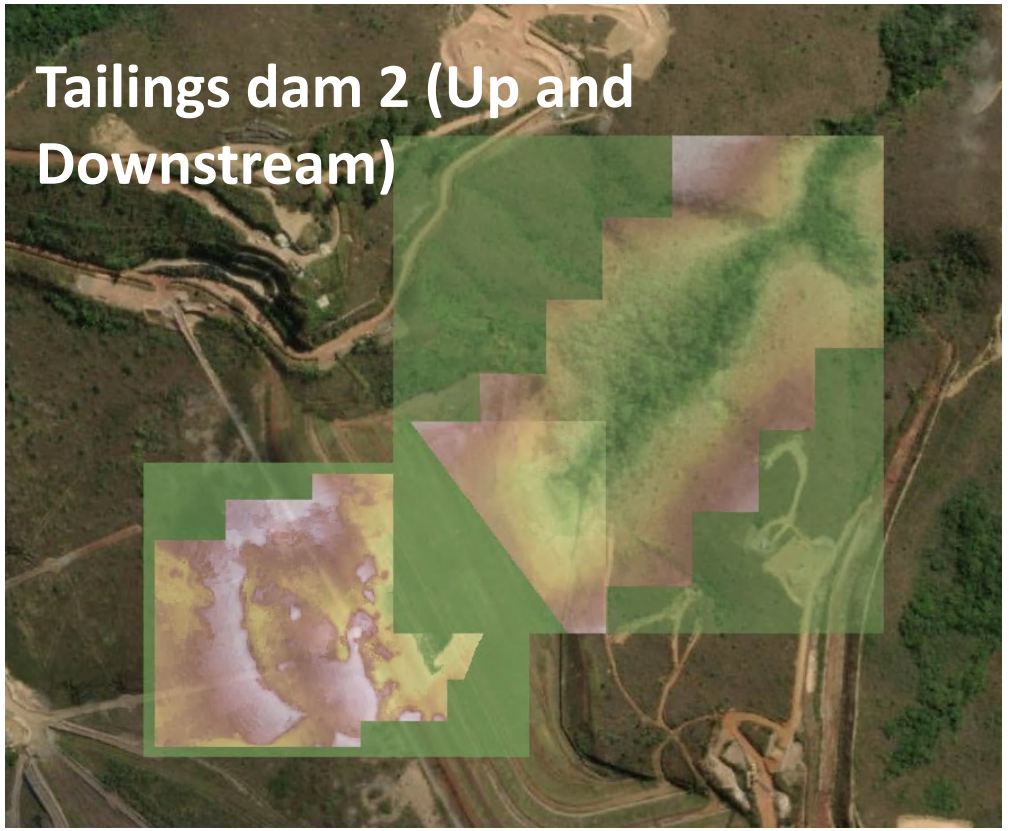
Optimal flight geometry and SAR band for achieving study goals

Choose the most suitable refractive index for the target material

Identify the peak of subsurface reflection to guide processing

STEP 1: MAPPING THE SUBSURFACE WITH SAR



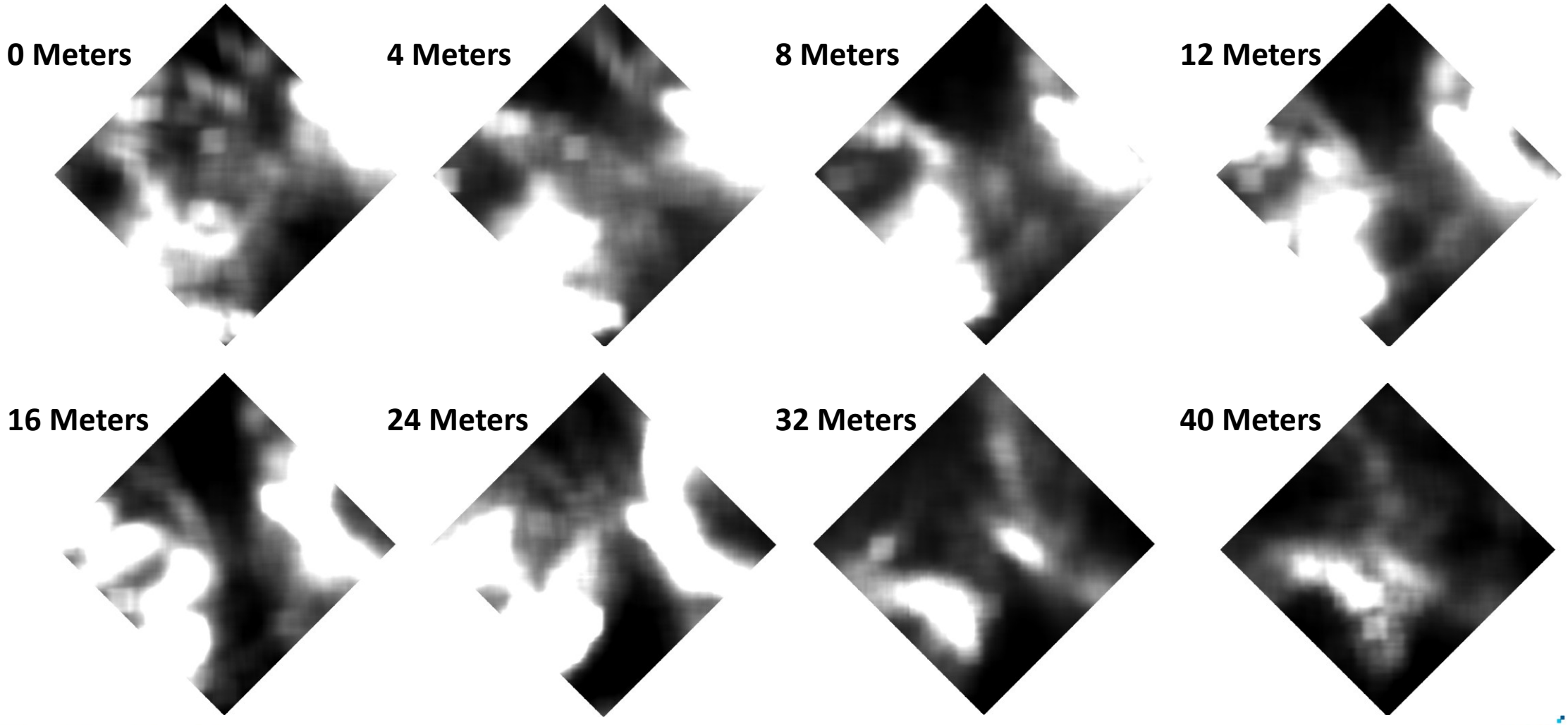


STEP 1: DATA ACQUISITION CHARACTERISTICS

SAR Tomography Specification example

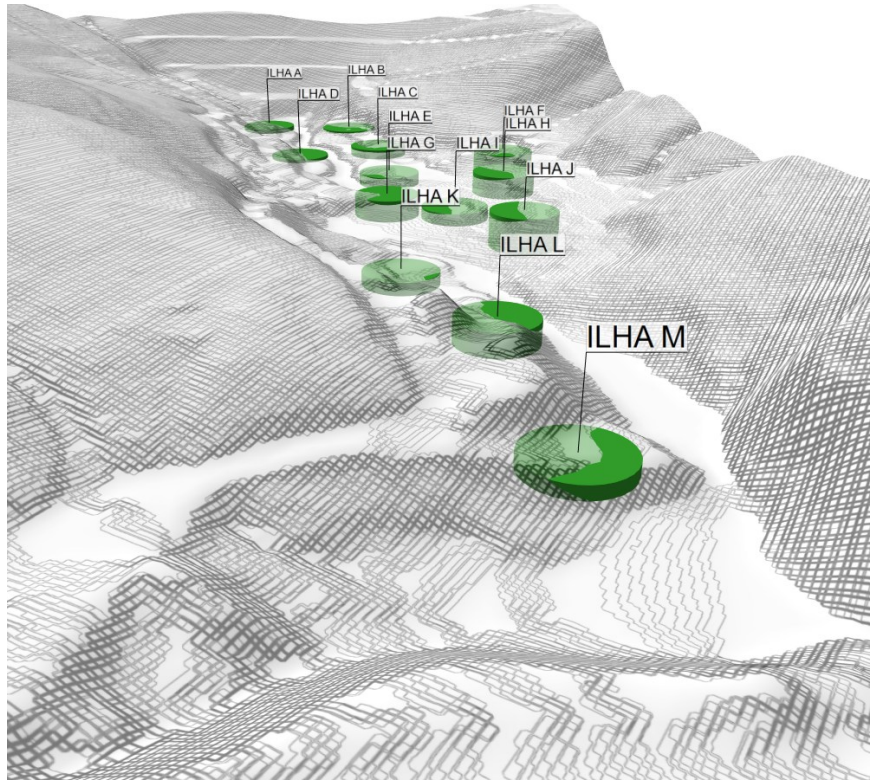
- **Conical orbit trajectory** with radii ranging from 115 to 165 meters;
- **Flight altitudes between 80 and 120 meters**, enabling optimal illumination of a 100 × 100 m^2 subsurface volume;
- **P-band processed** using a time-domain **back-projection algorithm**.
- **Planimetric resolution** of approximately **0.18 meters** for P-band SAR.

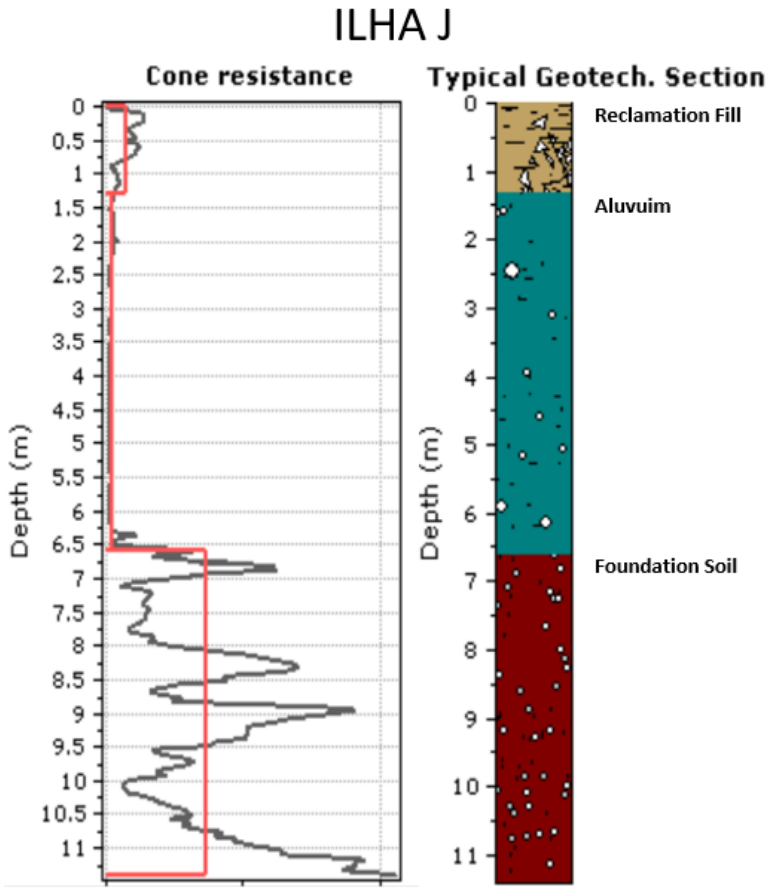
STEP 1: SAR TOMOGRAPHY AMPLITUDE SLICES



STEP 2: CREATING A WORKFLOW

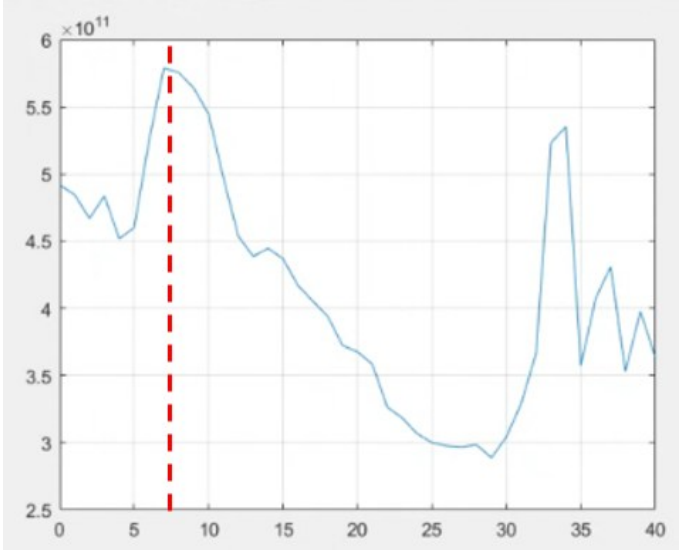
Representation of investigation points in the **study area**





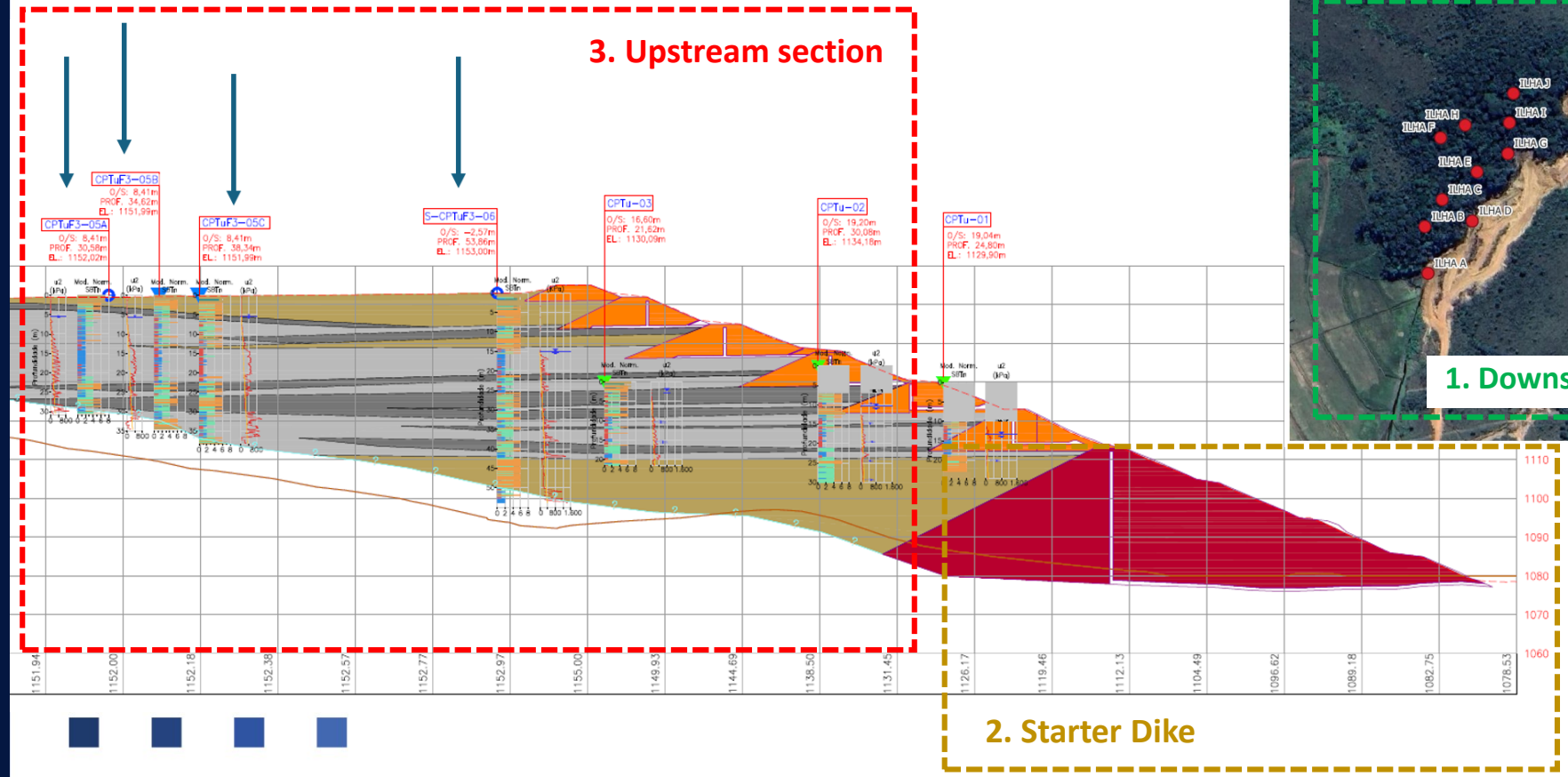
Representation of subsurface characteristics from an investigation point

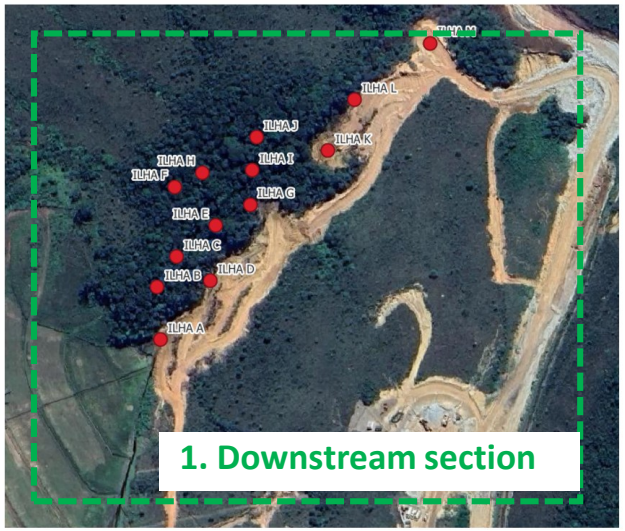
Representation of Reflectivity Behavior and Chosen Signal Peak



STEP 2: CHOOSING THE SPATIAL REFERENCES

- **Subsurface reference information** to adjust and validate SAR Tomography processing: **geologic profiles and investigation points** (STP or CPTU)

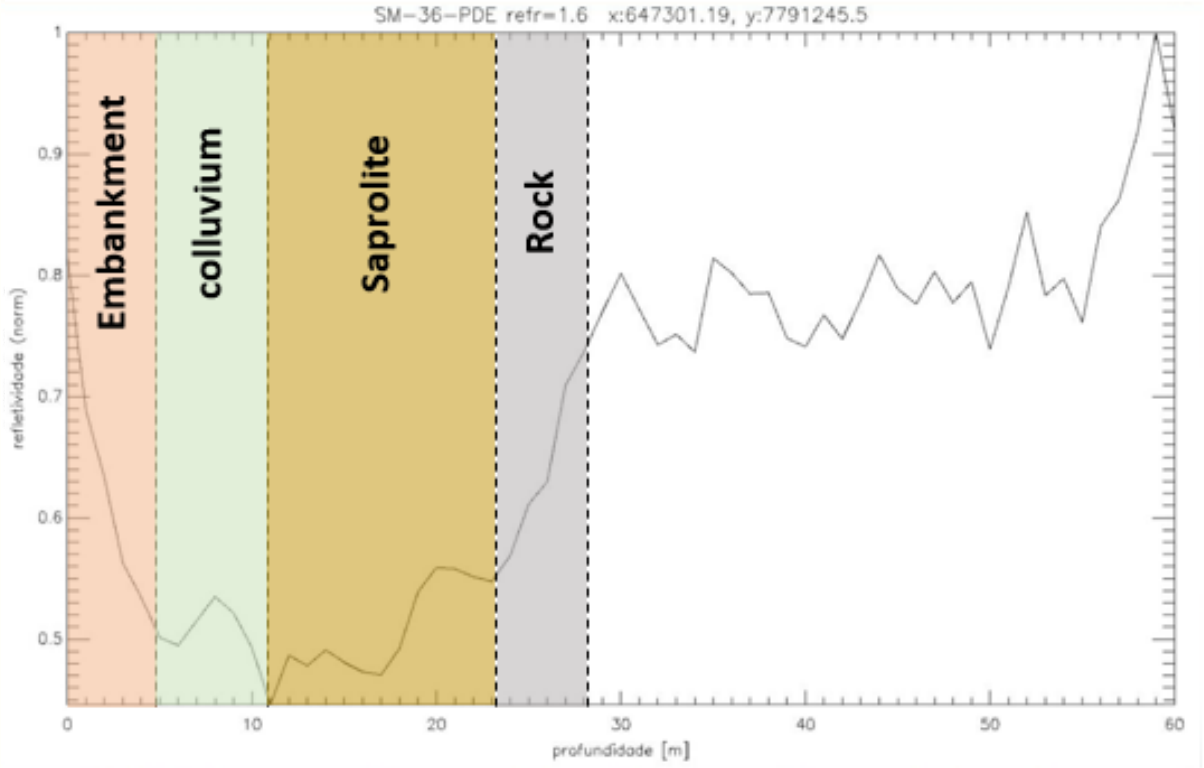


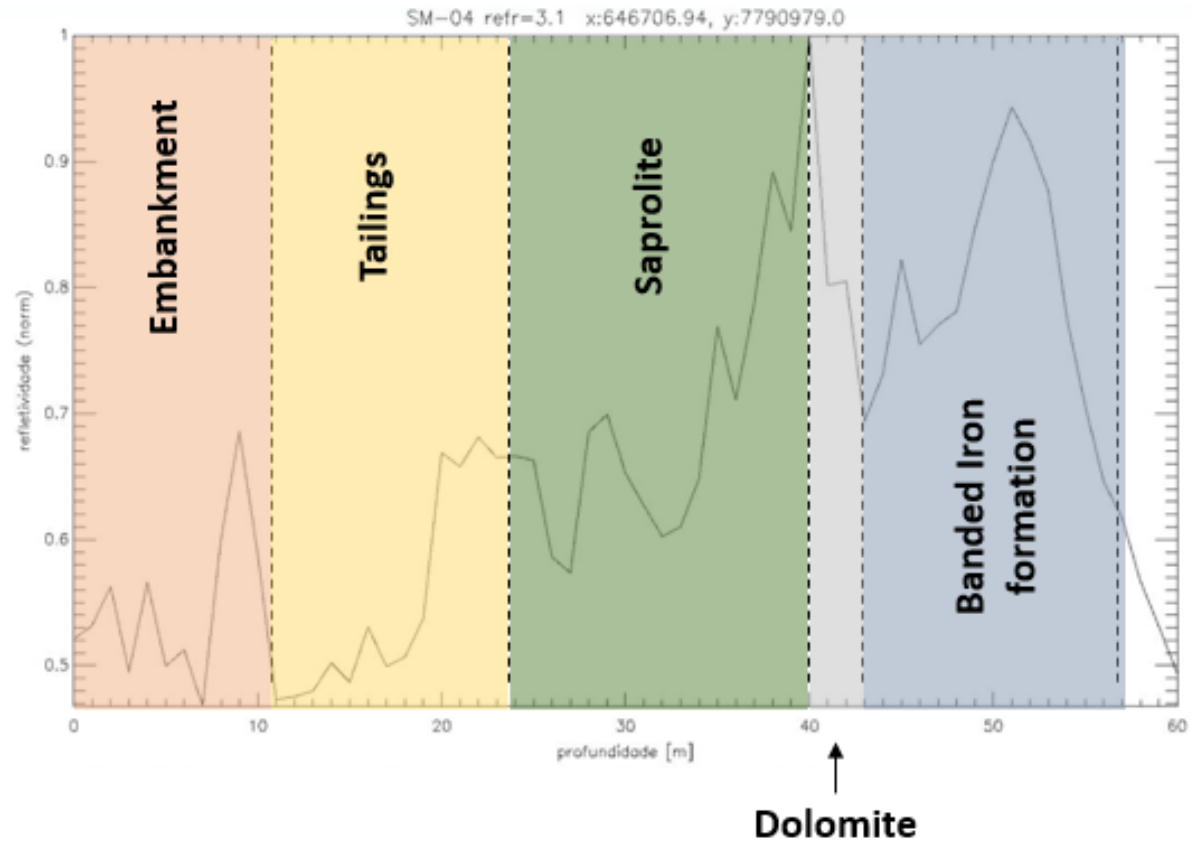


ILHA	Nome	Coordenadas		Profundidade (m)
		N	E	
ILHA - A	SCPTU-07	7 742 763,42	621570,75	1,61
ILHA - A	SCPTU-07A	7 742 763,87	621571,78	1,87
ILHA - A	SCPTU-07B	7 742 766,09	621570,47	4,12
ILHA - A	SCPTU-07C	7 742 765,66	621570,00	1,91
ILHA - B	SCPTU-07D	7 742 800,63	621566,48	1,48
ILHA - B	SCPTU-07E	7 742 802,80	621569,32	2,98
ILHA - B	SCPTU-07F	7 742 804,30	621570,32	5,49
ILHA - C	SCPTU-08F	7 742 824,13	621580,82	5,12
ILHA - C	SCPTU-08G	7 742 825,62	621584,22	8,28
ILHA - D	SCPTU-08	7 742 807,64	621607,43	3,15
ILHA - D	SCPTU-08A	7 742 803,89	621606,20	3,14
ILHA - D	SCPTU-08B	7 742 803,15	621608,57	1,08
ILHA - D	SCPTU-08C	7 742 806,70	621607,13	1,11
ILHA - D	SCPTU-08D	7 742 809,38	621607,12	1,57
ILHA - D	SCPTU-08E	7 742 806,46	621606,18	3,09
ILHA - E	SCPTU-08H	7 742 847,54	621611,19	3,51
ILHA - F	SCPTU-08I	7 742 874,62	621580,11	10,80
ILHA - F	SCPTU-08J	7 742 876,17	621582,68	11,37
ILHA - G	SCPTU-09	7 742 860,86	621635,50	12,99
ILHA - G	SCPTU-09A	7 742 863,98	621637,07	8,36
ILHA - H	SCPTU-11	7 742 886,43	621601,31	7,69
ILHA - H	SCPTU-11A	7 742 884,94	621602,04	7,60
ILHA I	SCPTU-10E	7 742 889,09	621637,71	3,64
ILHA I	SCPTU-10F	7 742 885,47	621637,79	3,90
ILHA J	SCPTU-10B	7 742 914,78	621641,24	10,41
ILHA J	SCPTU-10C	7 742 911,88	621639,90	4,51
ILHA J	SCPTU-10D	7 742 912,80	621642,60	11,12
ILHA J	SCPTU-10G	7 742 907,77	621640,18	8,39
ILHA J	SCPTU-10H	7 742 909,62	621638,88	11,49
ILHA K	SCPTU-10	7 742 901,09	621691,42	5,40
ILHA K	SCPTU-10A	7 742 902,30	621693,41	2,44
ILHA L	SCPTU-12	7 742 940,40	621714,18	5,28
ILHA L	SCPTU-12A	7 742 936,96	621711,19	6,20
ILHA L	SCPTU-12B	7 742 937,61	621710,20	4,18
ILHA M	SCPTU-13	7 742 983,80	621762,64	4,25
ILHA M	SCPTU-13A	7 742 976,56	621769,41	1,17
ILHA M	SCPTU-13B	7 742 977,92	621767,95	1,26

STEP 2: UNDERSTAND THE SIGNAL ALONG DEPTH

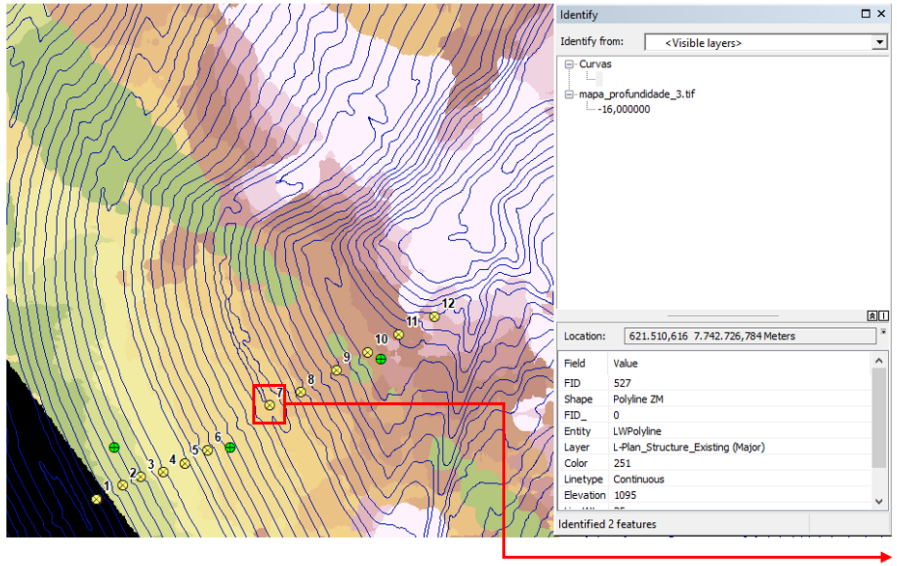
- SAR Tomography **signal behavior along depth** in sample points





STEP 3: COMPARING AND ADJUSTING SAR DATA

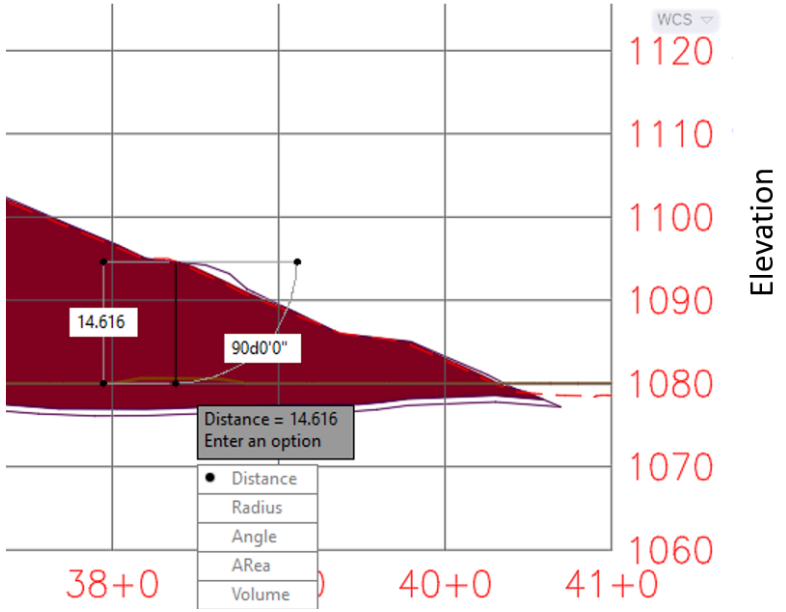
- **Compare the reference information** with SAR Tomography processing

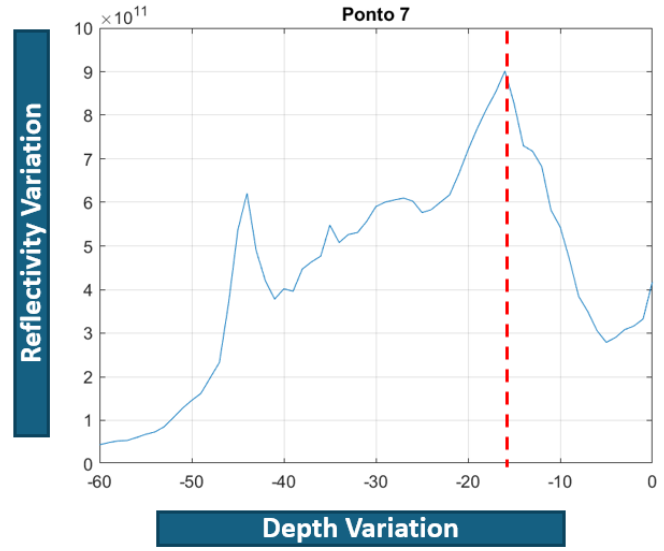


Point investigation

- Topographic elevation = 1095 m
- Depth identified in the geologic profile (CAD) = 14.6
- Depth identified by radar = 16 m

Comparison of selected points
GIS vs. CAD profile

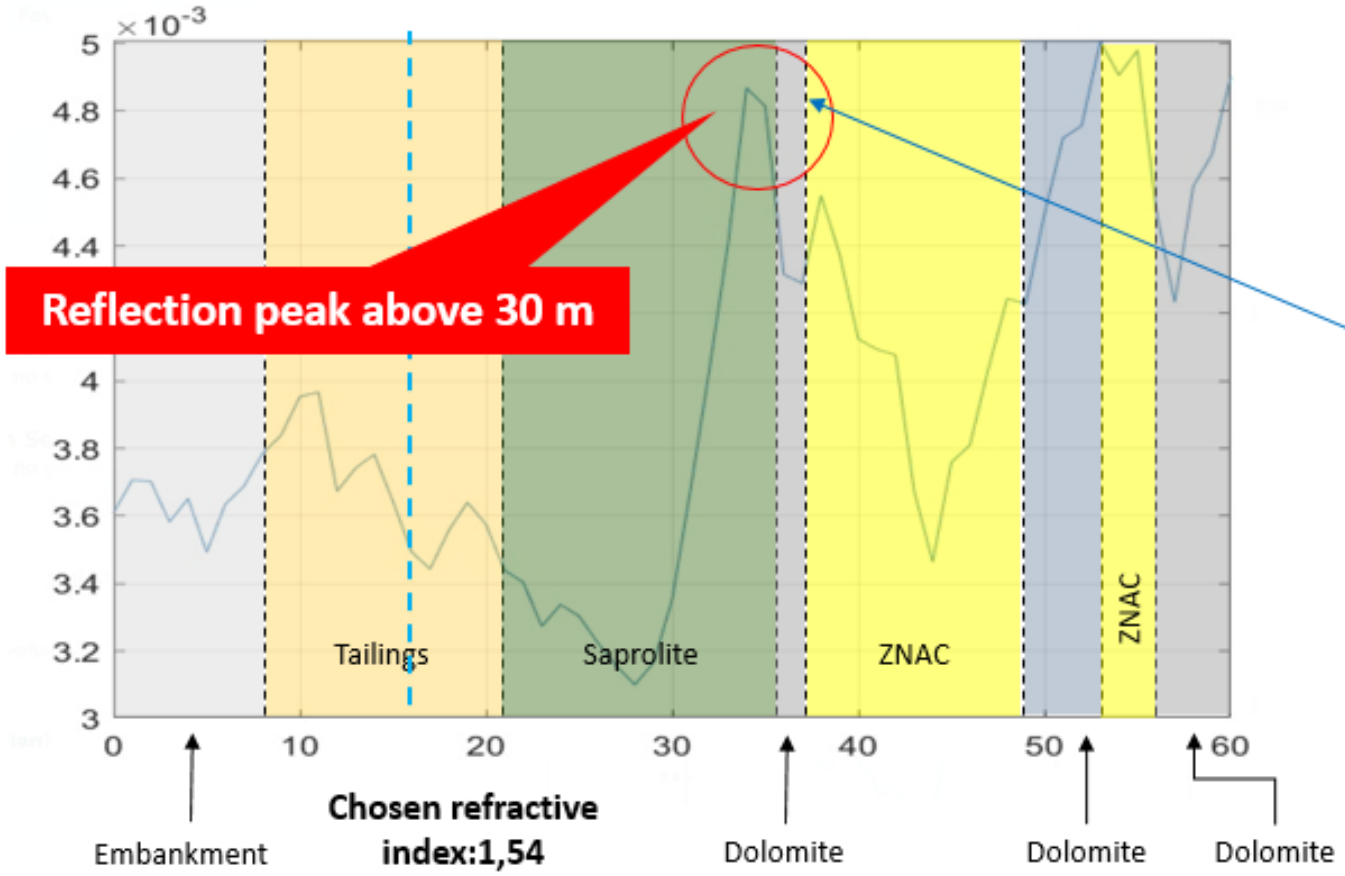


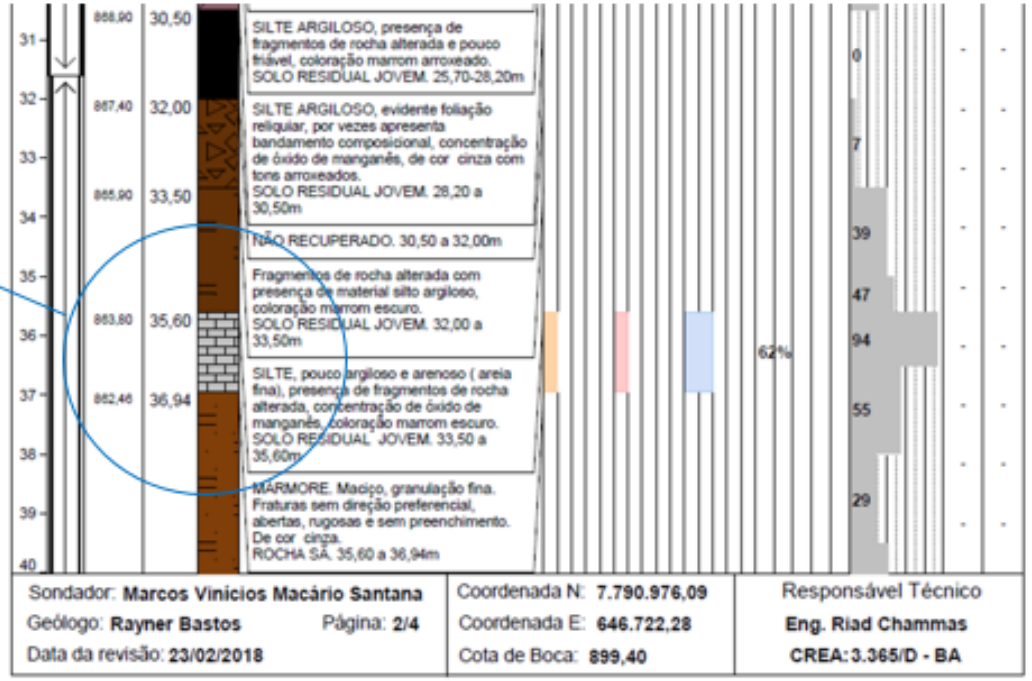


Representation of Reflectivity Behavior and Chosen Signal Peak

STEP 3: IDENTIFYING THE TARGET

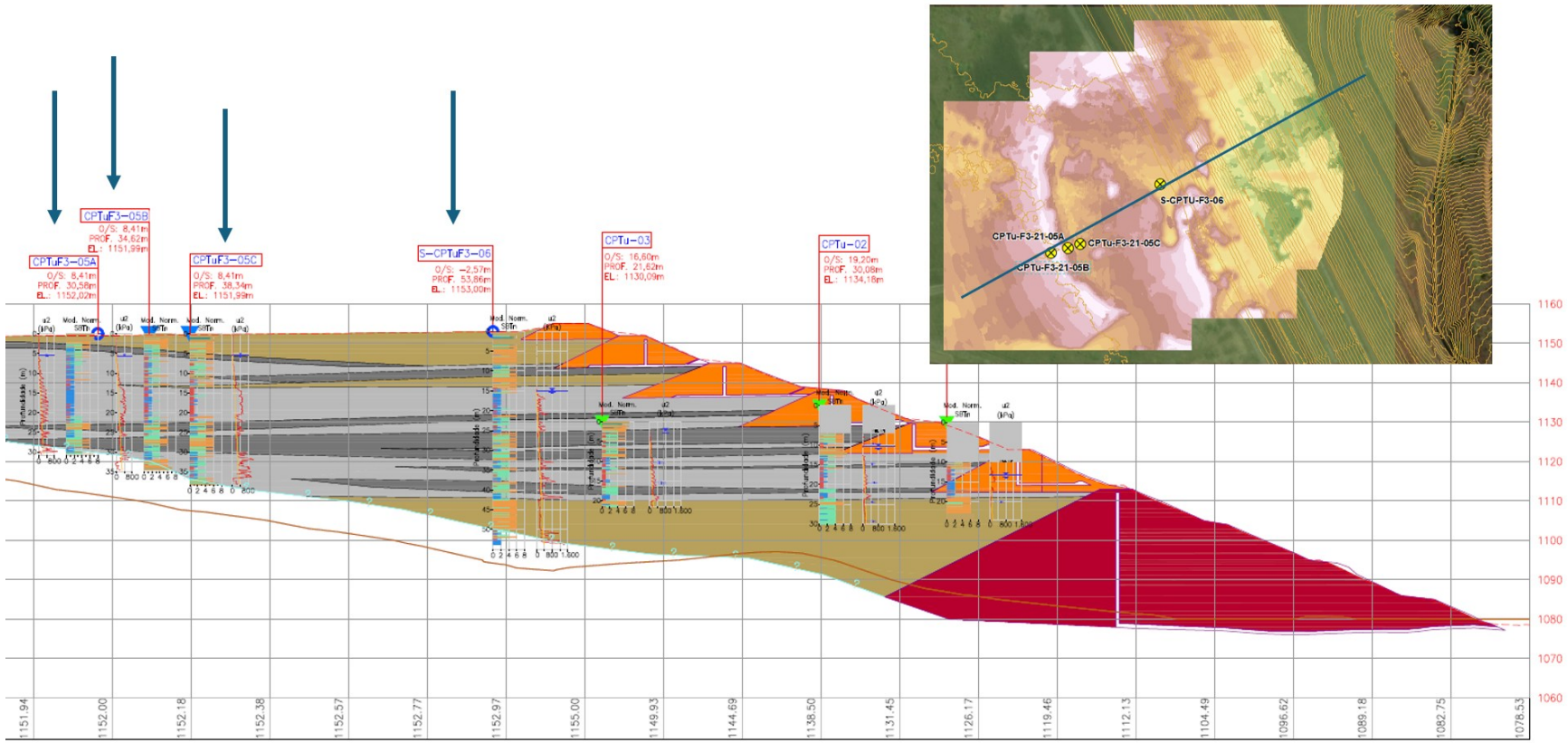
- **Reflection peak of SAR signal** indicating the target subsurface

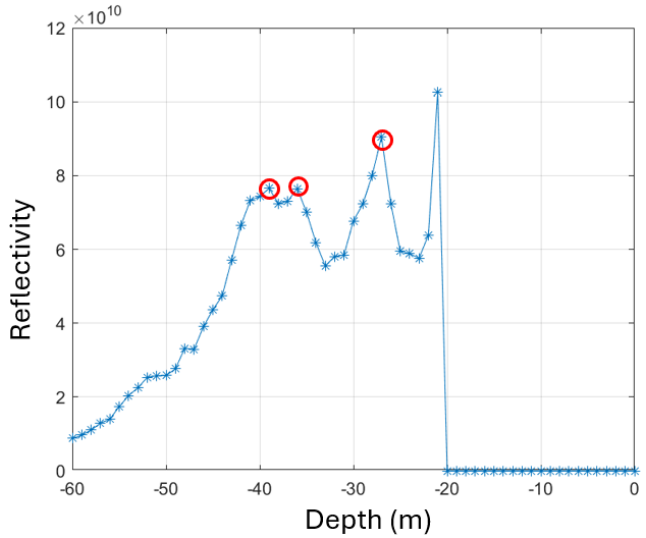




STEP 3: FINDING THE BEST ADJUSTMENT

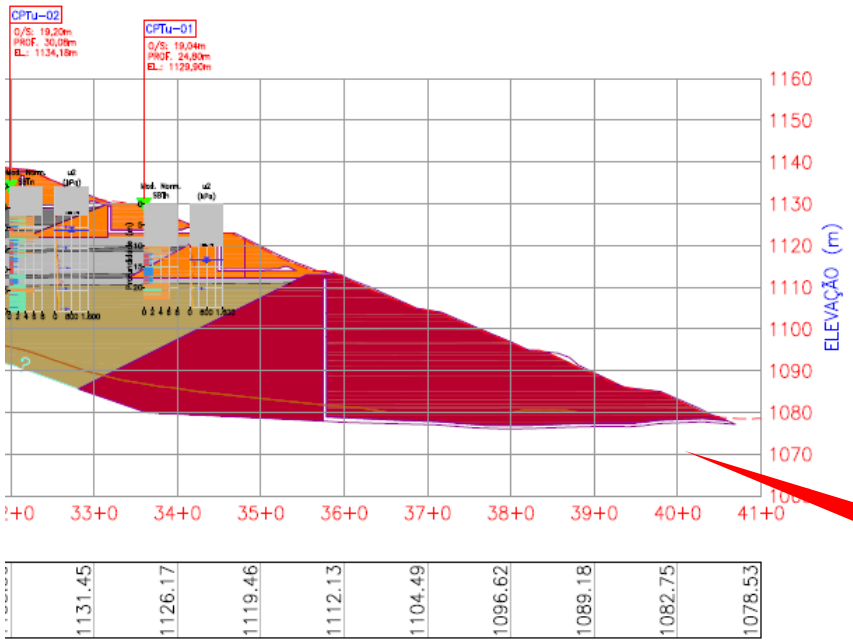
- Example depth profile excluding data from 0 to –20 meters; red circles in the graph indicate peaks, with the deepest at 39 meters.

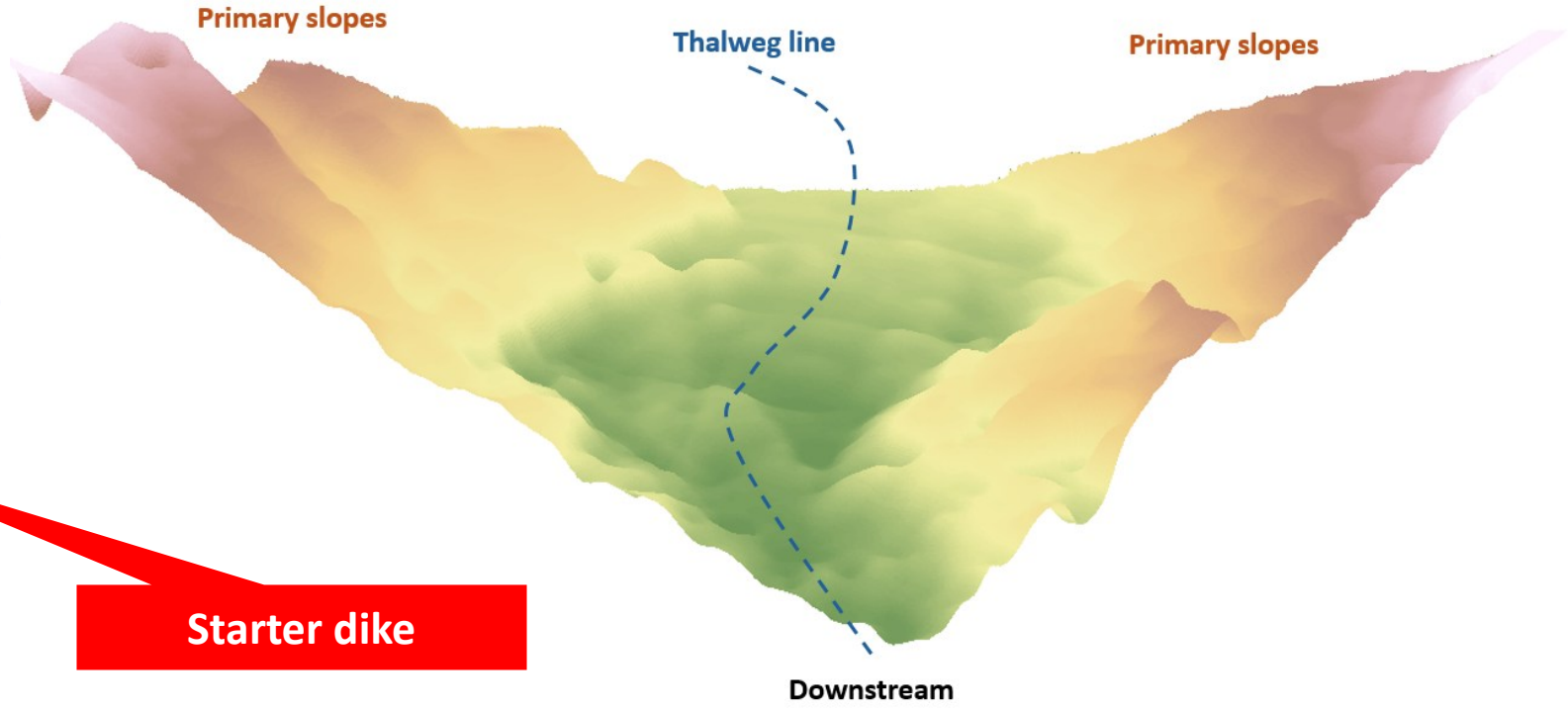




STEP 4: EXTRAPOLATING SAR DATA

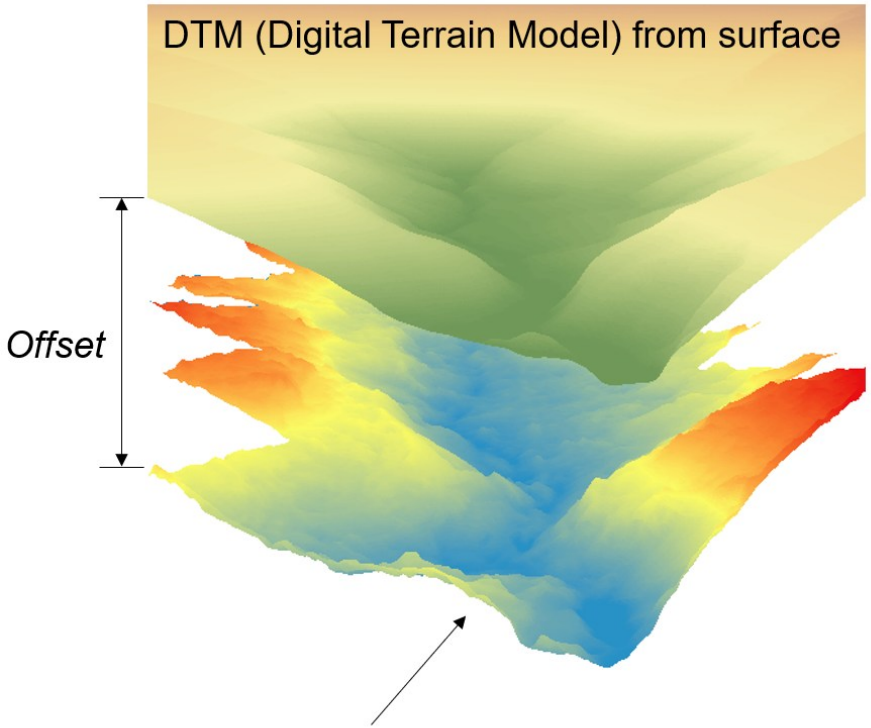
- Generated **subsurface model** corresponding to the **foundation soil layer** estimated from geologic profile.



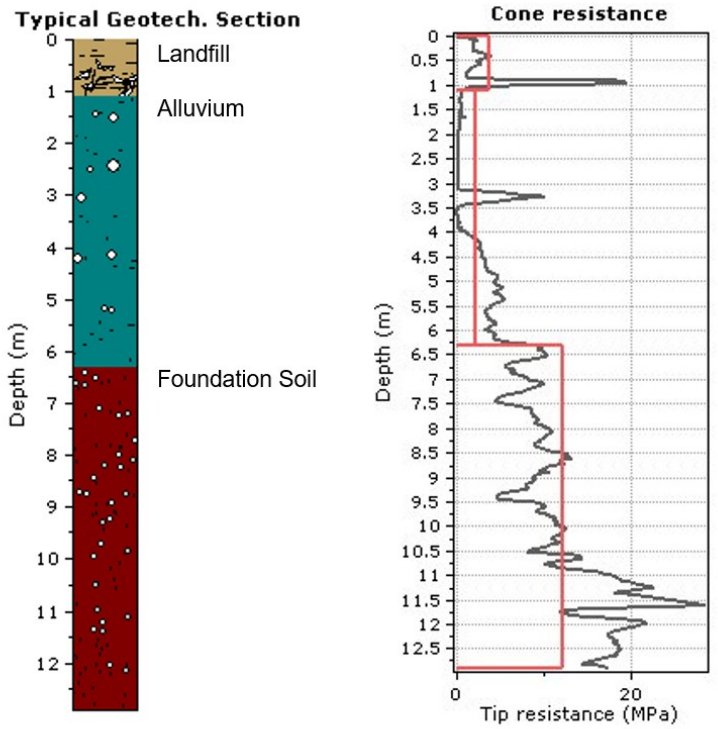


STEP 4: EXTRAPOLATING SAR DATA

- Generated **subsurface model** corresponding to the **foundation soil layer** estimated from CPTU data.



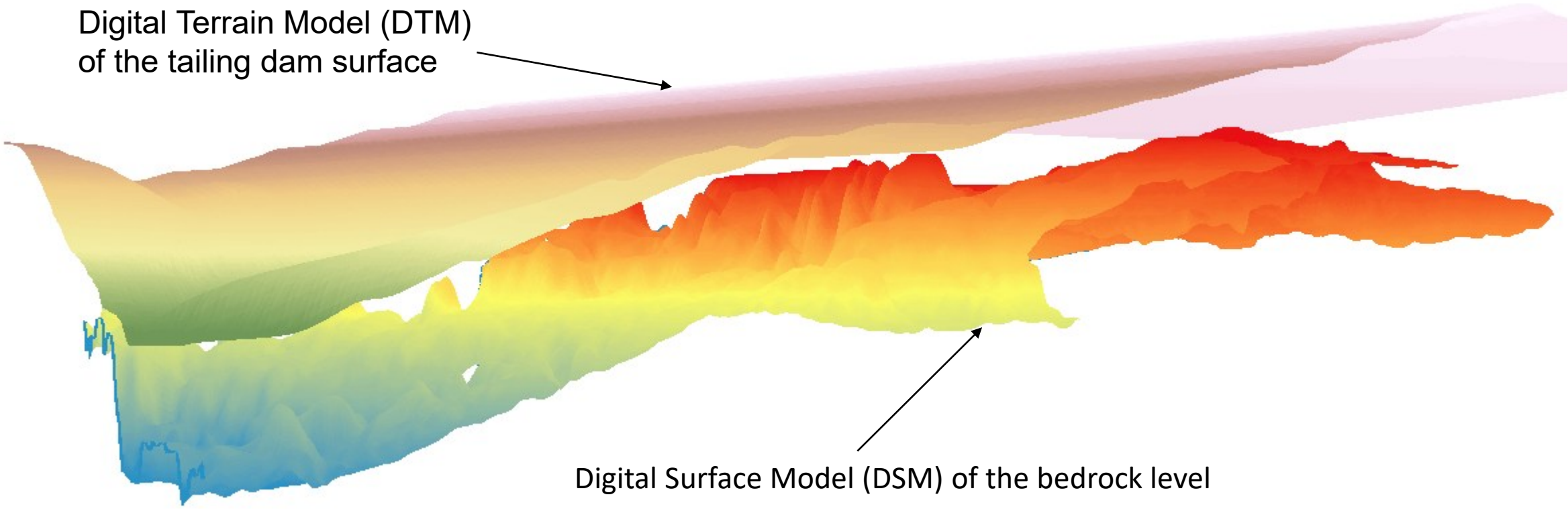
Estimated foundation Soil (more competent layer)



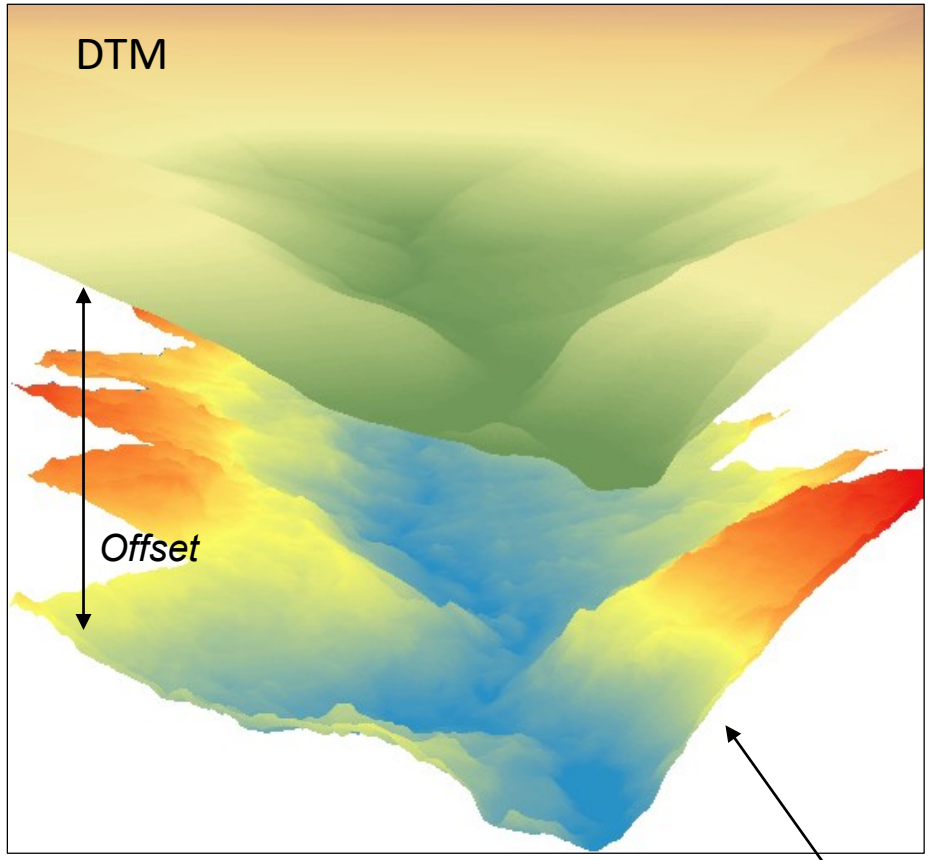
Layer depths estimated from CPTU

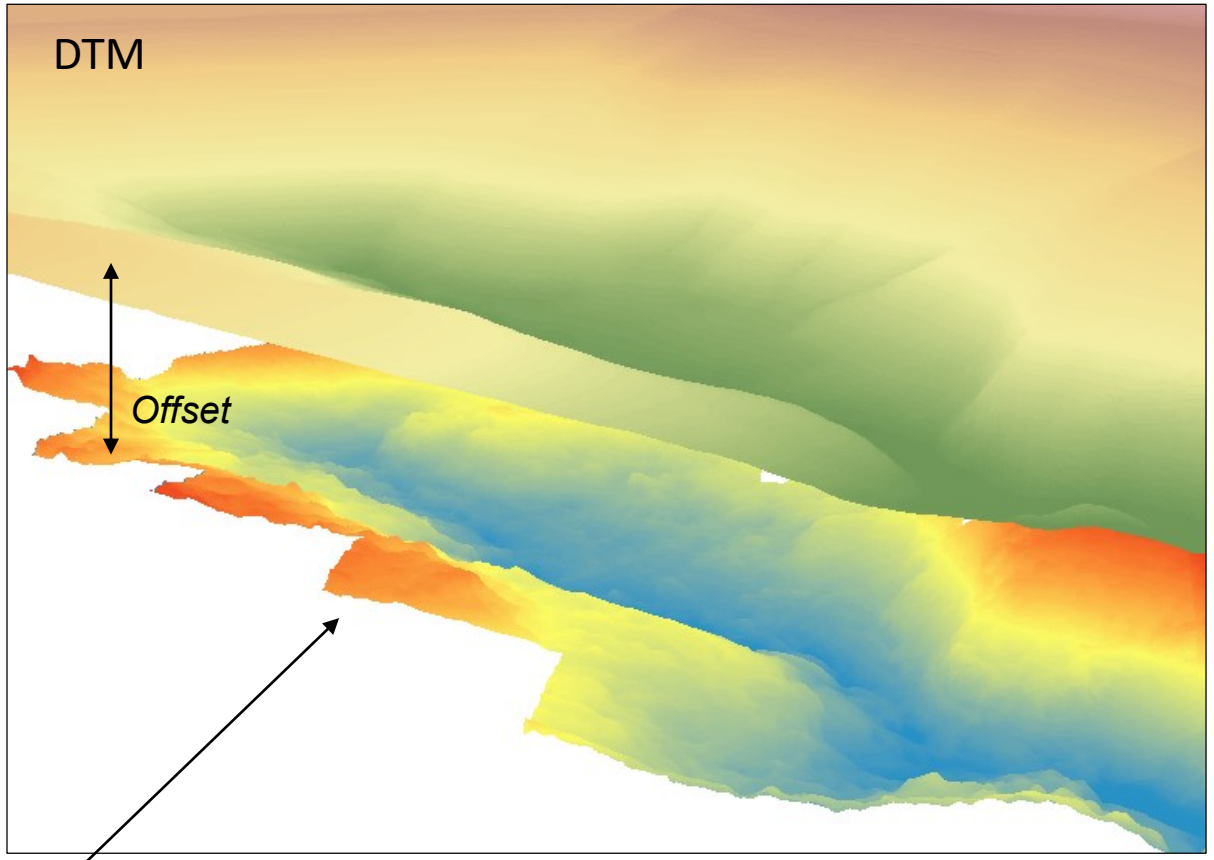
STEP 4: EXTRAPOLATING SAR DATA

- Generated **subsurface model** corresponding **to the bedrock layer** estimated from SCPTU data.



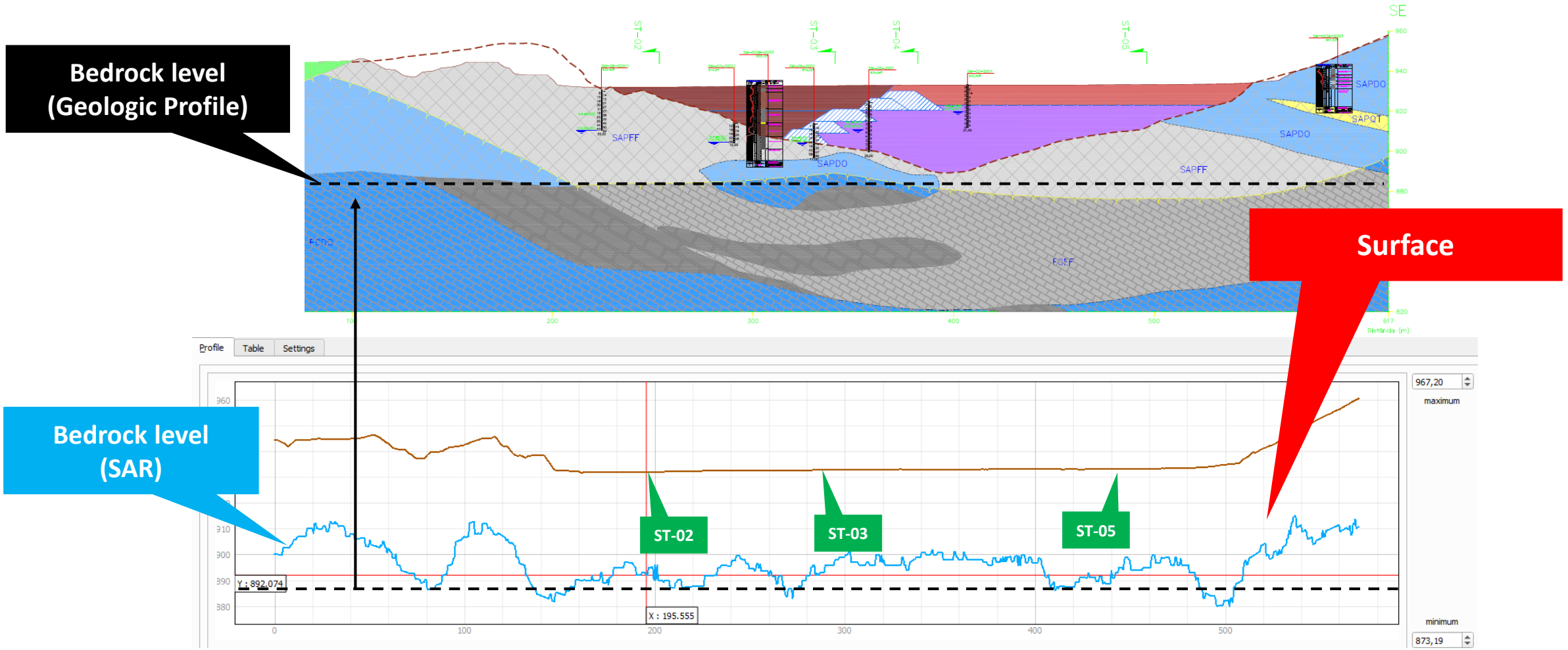
RESULTS: FOUNDATION SOIL MAPPED



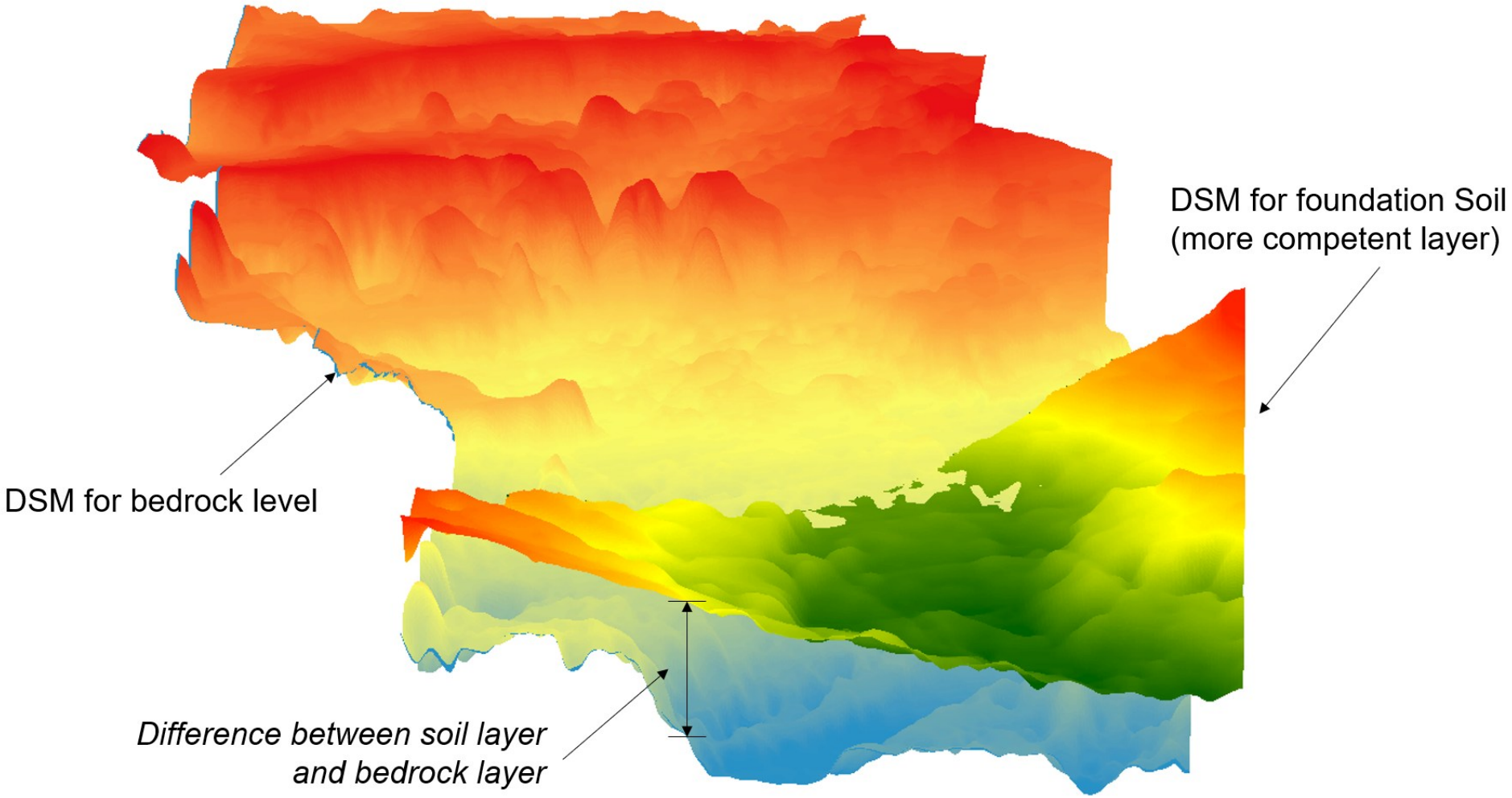


Estimated foundation Soil (more competent layer)

RESULTS: MAPPED BEDROCK LEVEL

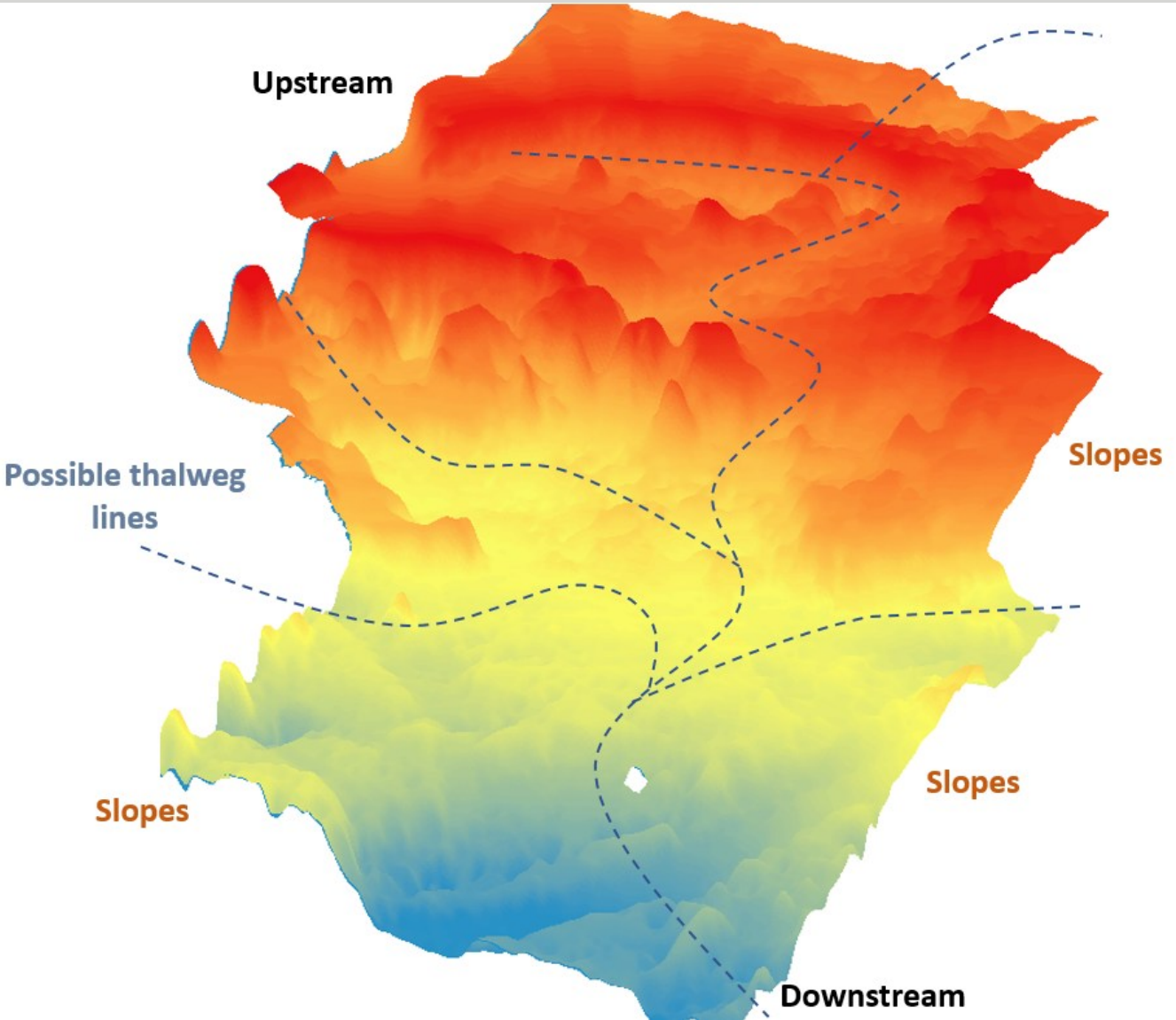


RESULTS: MULTIPLE LAYERS IDENTIFIED



RESULTS: ESTIMATED SUBSURFACE MORPHOLOGY

- Aerial photograph analysis revealed a drainage pattern consistent with expected geomorphology.



CONCLUSIONS

- **SAR Tomography successfully distinguished** distinct subsurface layers.
- **The strategy of selecting** an appropriate refractive index and estimated depth for the target layer **proved effective**.
- SAR data processing **can determine the depth of multiple layers**, whether fresh or weathered rock, or competent soil.
- Combined with the operational ease of a drone-borne SAR system, **UAV-SAR is a powerful tool for mapping shallow subsurface materials**.

NEW CHALLENGES

- Can I consider **SAR Tomography** as actual tomographic mapping? Or should we use different terminology?

- Are we successfully identifying targets located at depths of 50 to 60 meters? Up to what point can we consider the mapping of information below that depth to be accurate?

- We achieved successful results with foundation soil and with bedrock layers. Which materials could potentially be identifiable? Could we succeed in mapping voids between the rocks?

Thank you!

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