

INGEMMET experience in using Remote Sensing for geological mapping and mineral prospecting

Katherine Gonzales

Remote Sensing Laboratory

Laboratory Directorate

INGEMMET



Content

- ❖ Introduction
 - ✓ INGEMMET Remote Sensing Laboratory
- ❖ INGEMMET experience in using Remote Sensing
 - ✓ RS in geological mapping
 - ✓ RS in mineral prospecting
 - ✓ RS in environmental impact of mining
- ❖ Perspectives

Content

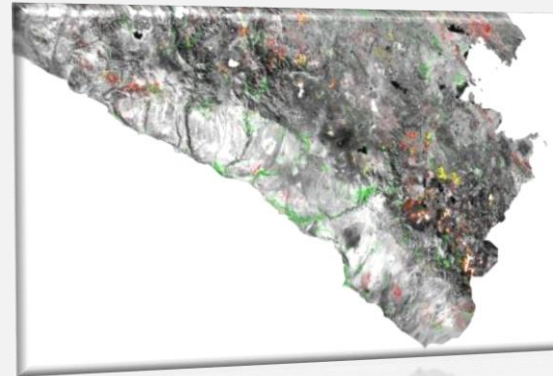
- ❖ Introduction
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- ❖ Perspectives

Introduction – INGEMMET Remote Sensing Laboratory

- Is one of the 5 laboratories of Laboratory Directorate

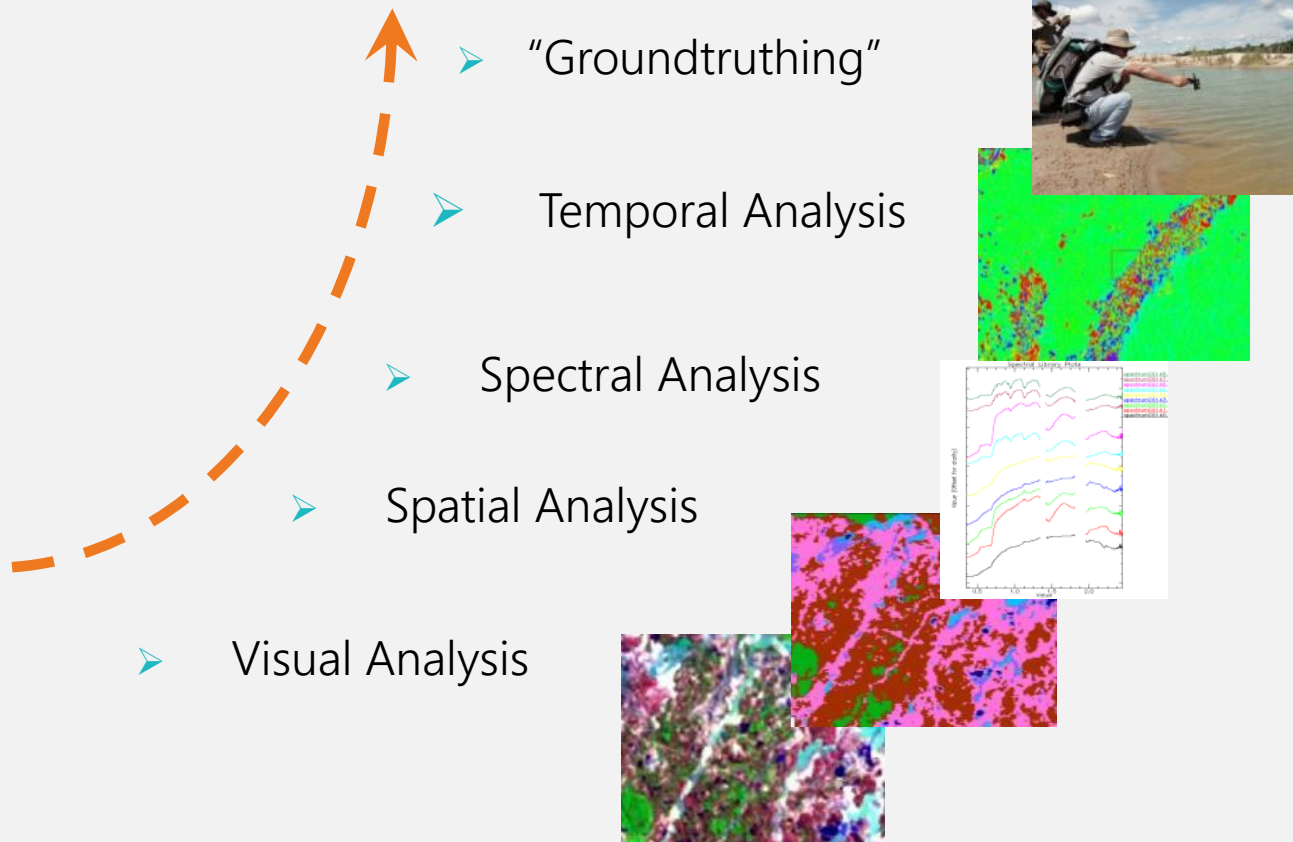
Laboratory facilities and equipment:

- Satellite images (optical & radar)
- Workstations and big format printing
- Radiometers (VNIR-SWIR-TIR)
- GPS (GNSS and differential)



Introduction – INGEMMET Remote Sensing Laboratory

- Digital image analysis, processing and interpreting.



Equipment



Workstations



Radiometry
equipment



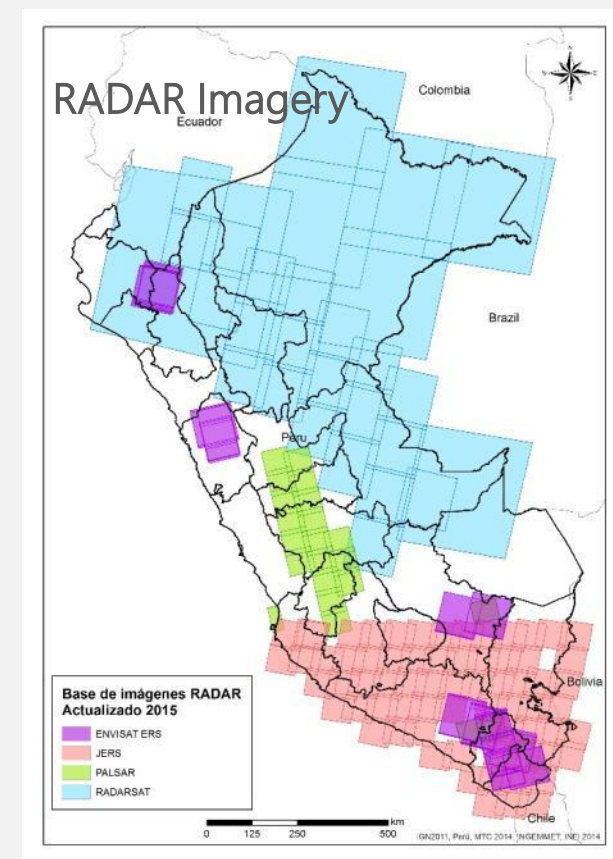
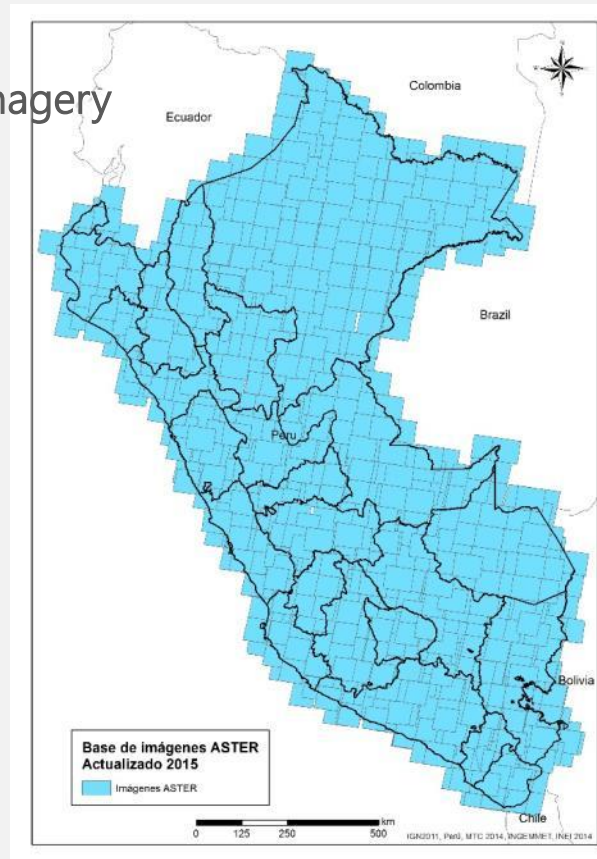
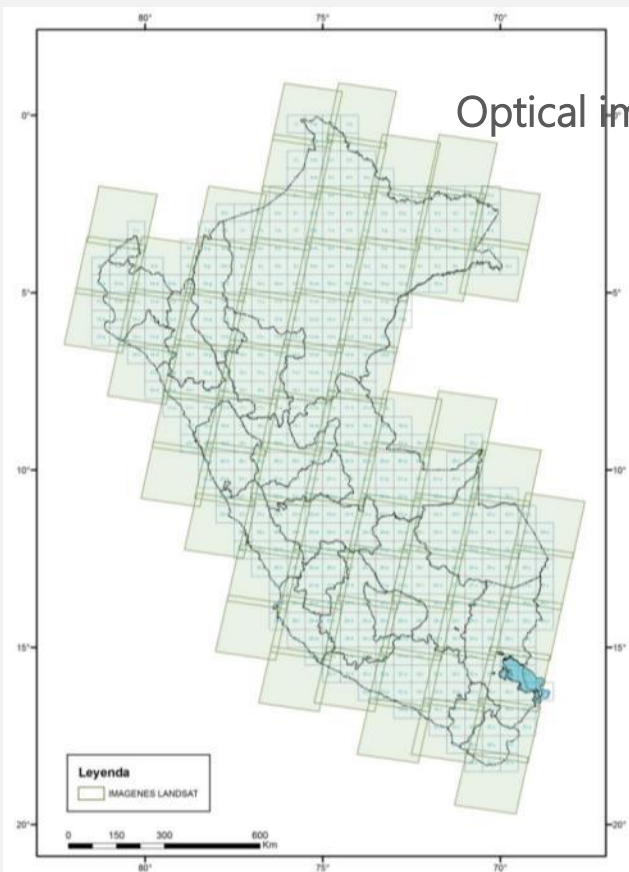
GPS



Introduction – INGEMMET Remote Sensing Laboratory

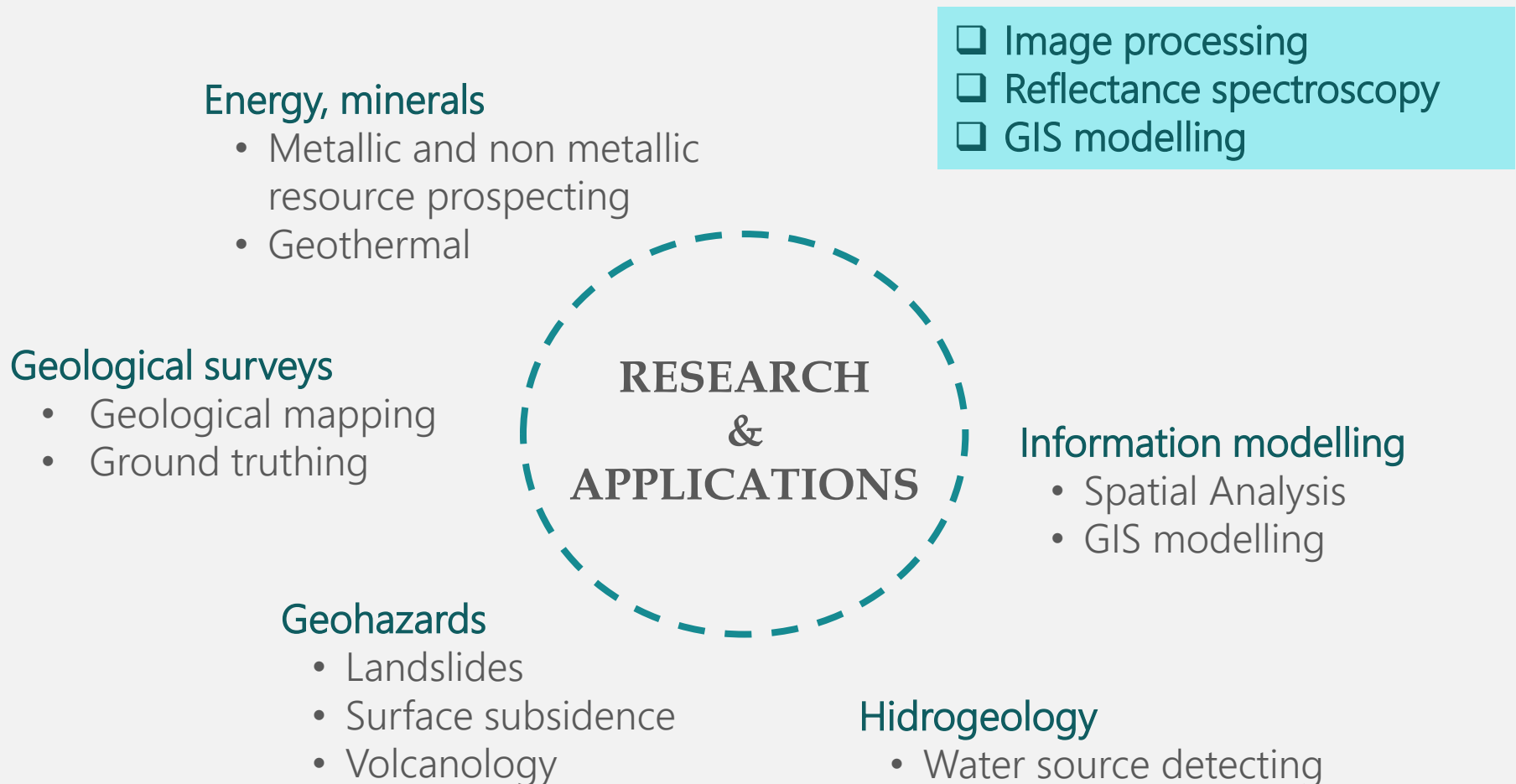
Satellite images database:

- Óptico: ASTER, LANDSAT-7, LANDSAT-8, RAPIDEYE
- Radar: TERRASAR-X, ALOS PALSAR, RADARSAT, JERS-1



Introduction – INGEMMET Remote Sensing Laboratory

❖ Main research activities and interests:



Content

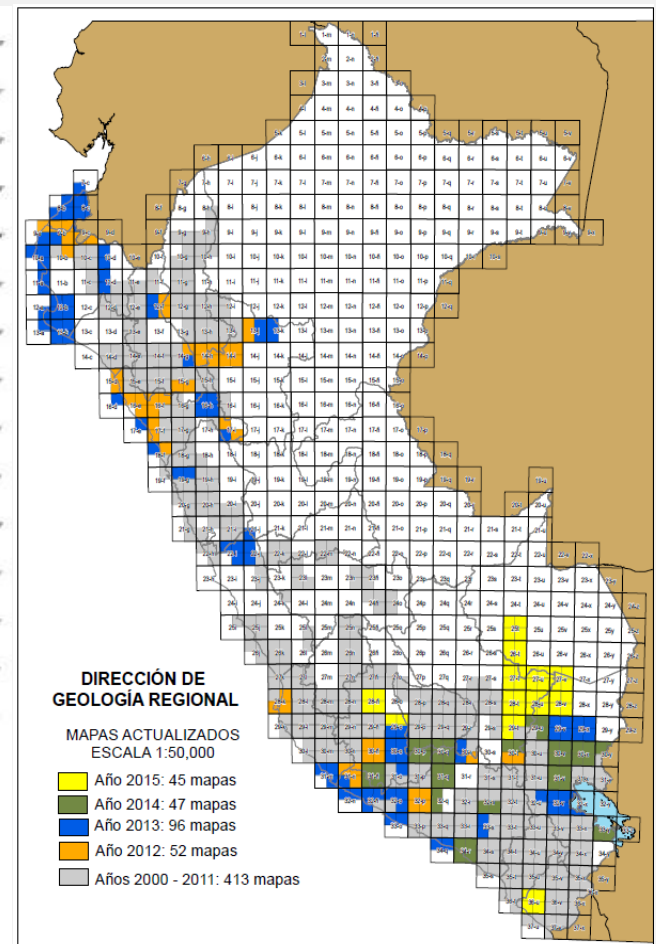
- ❖ Introduction
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 - ✓ RS in environmental impact of mining
- ❖ Perspectives

RS in geological mapping

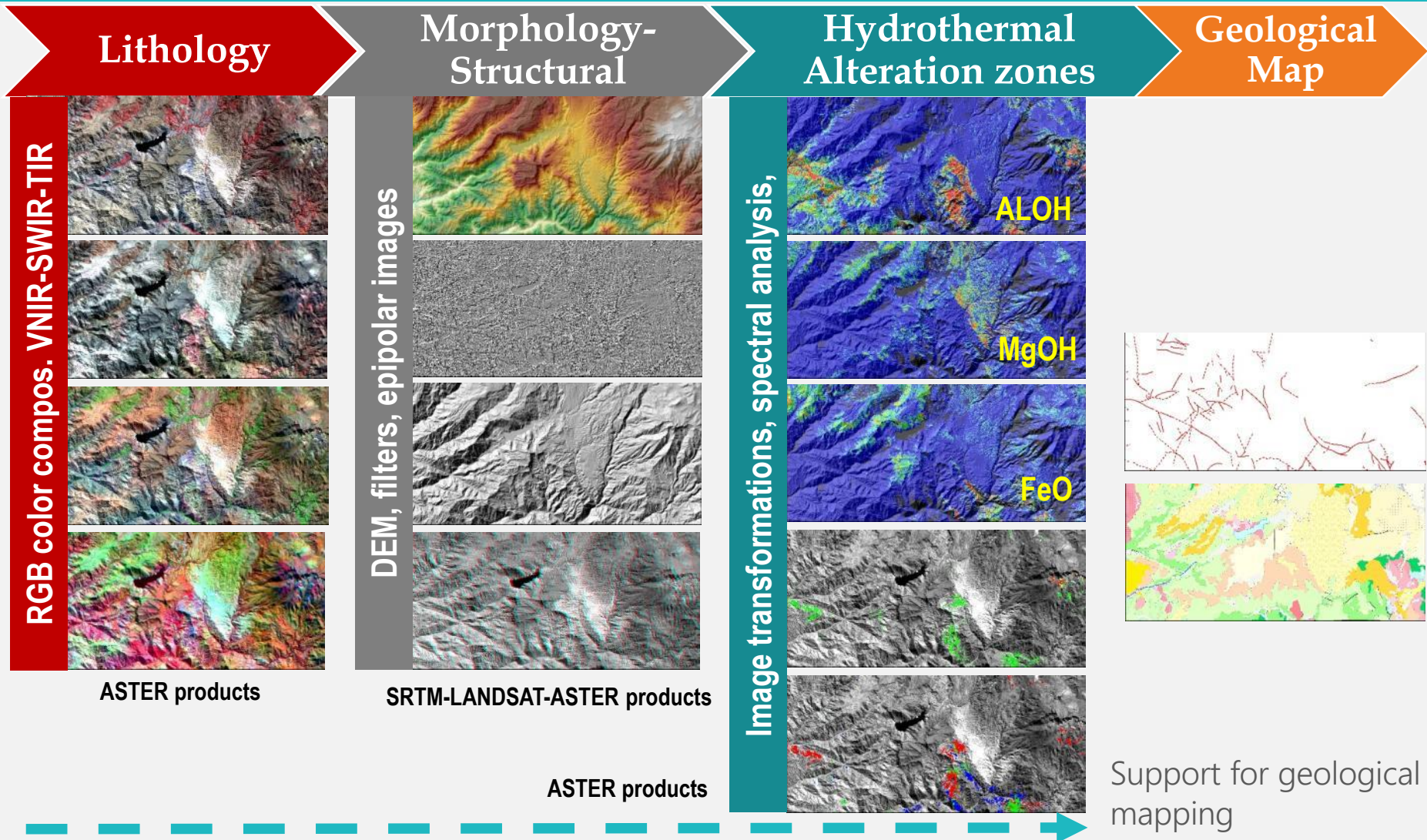
The Regional Geology Directorate (DGR) of INGEMMET is in charge of the NATIONAL GEOLOGICAL MAP

**Geological National
Map at 1:100,000**

-> 501 sheets

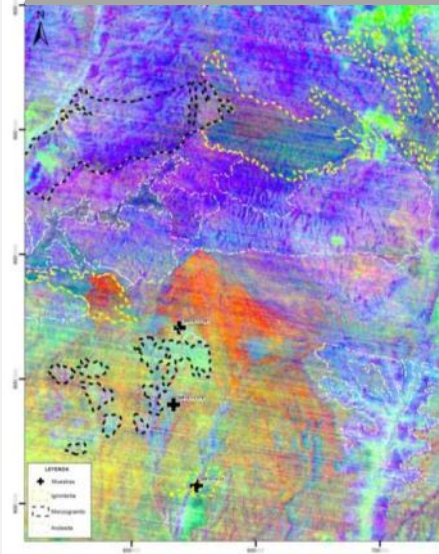


RS in geological mapping

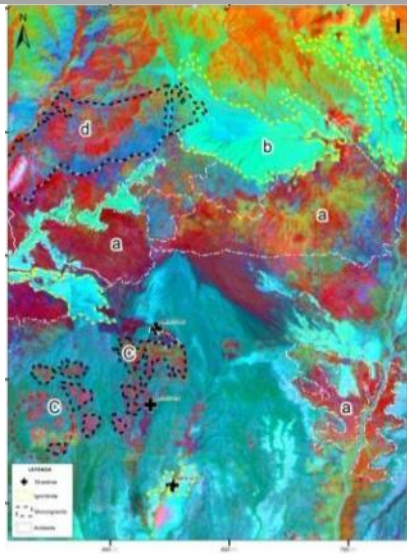


RS in geological mapping

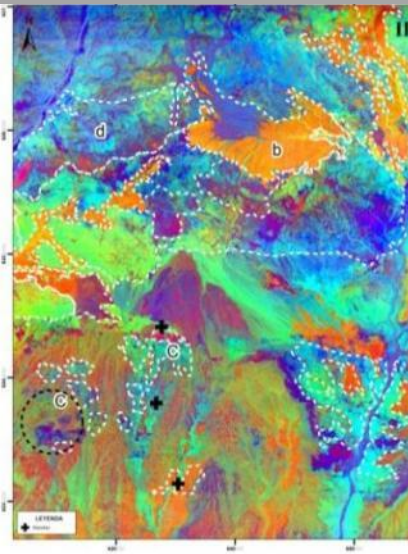
ASTER products



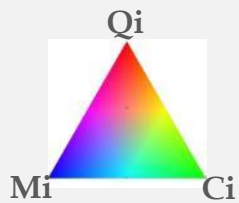
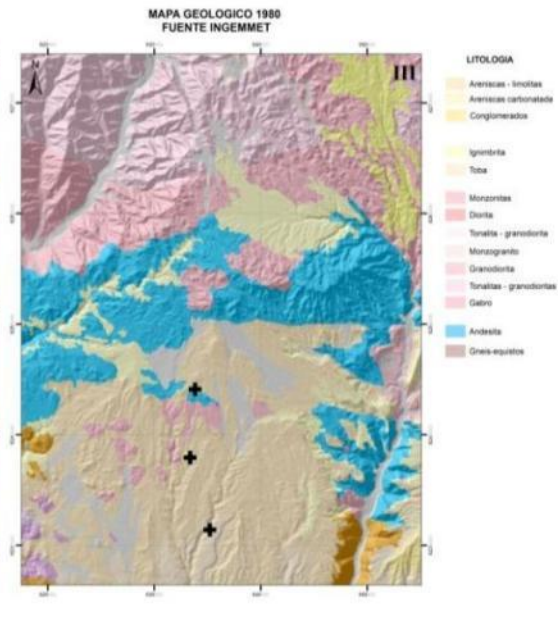
RGB:Qi,Ci,Mi



RGB:11,6,2



RGB:8/5,5/4,7/8



Fuente:
Cutipa et al., 2014

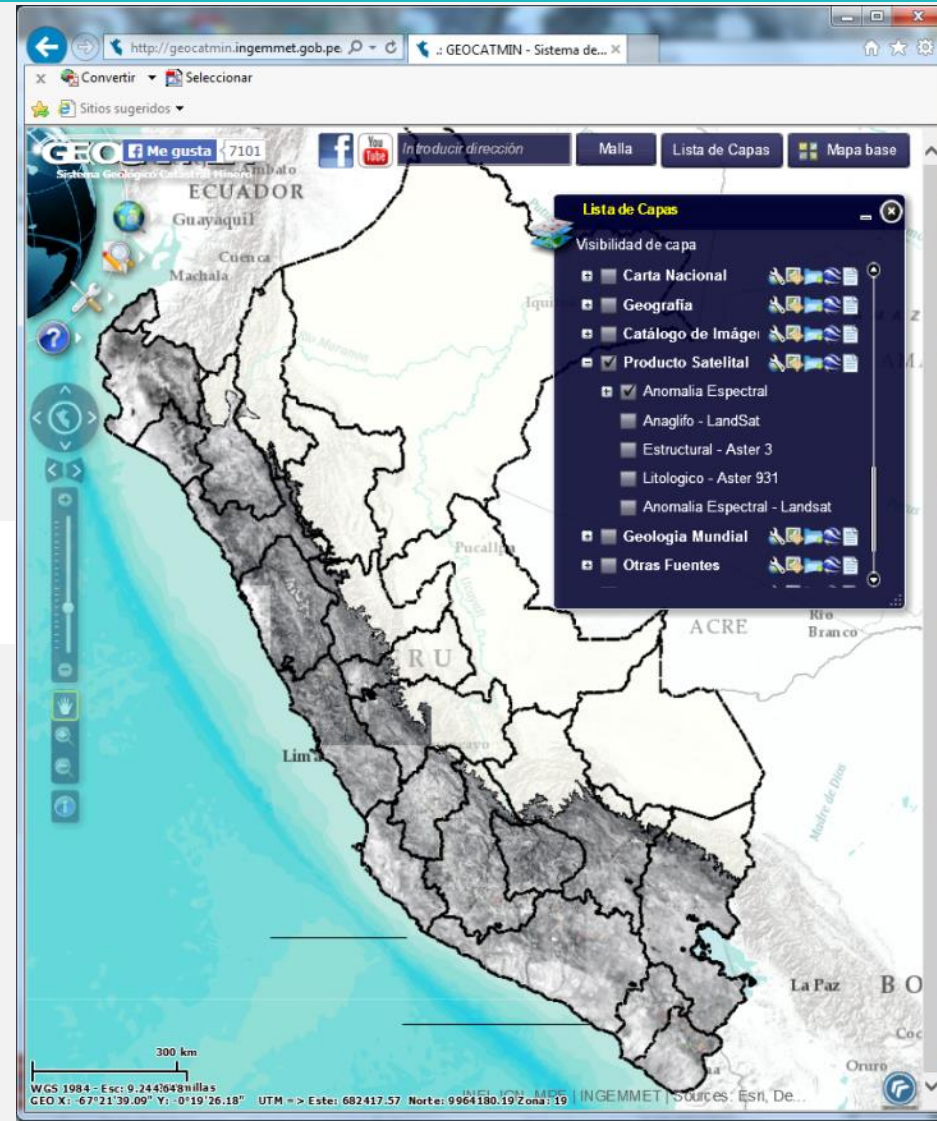
RS in geological mapping

GEOCATMIN (WMS)

<http://geocatmin.ingemmet.gob.pe/geocatmin/>

Available satellite products (1/100,000)

- **ASTER, RGB: 931**
- **ASTER, B3**
- **LANDSAT, oxides+clays map**
- **ANAGLIPH (LANDSAT+SRTM-30)**



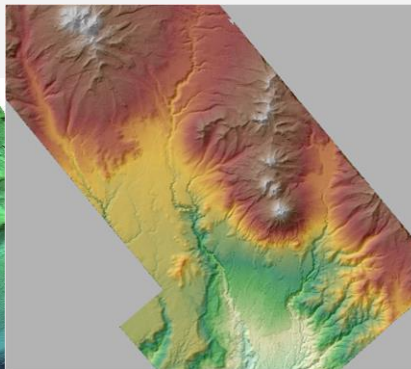
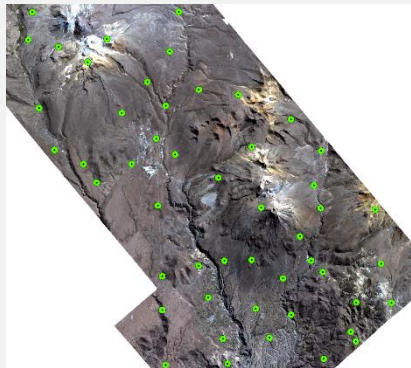
RS in geological hazards mapping

Morfology-Structural



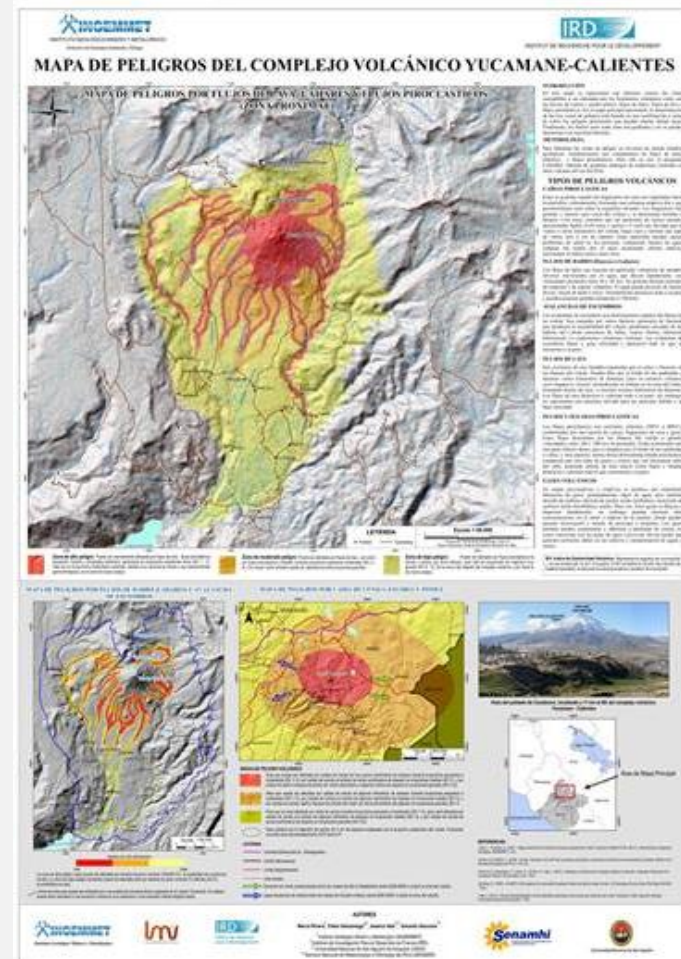
Geological hazards mapping

High resolution DEM



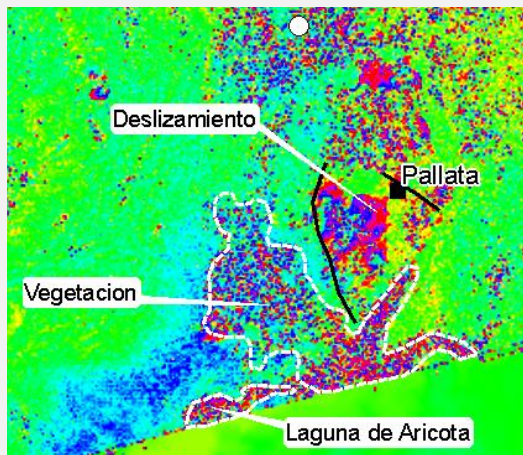
DEM from stereopairs
(SPOT 6)

Geological Hazard Map



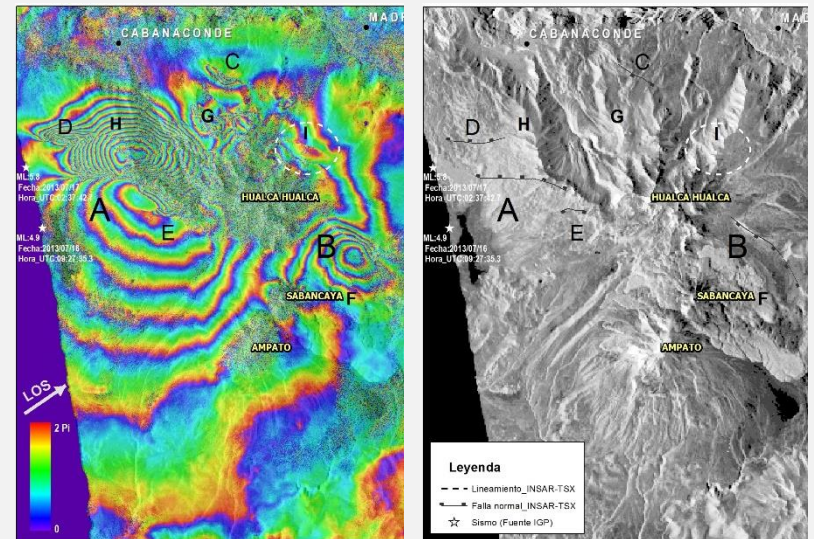
RS in geological hazards mapping

INSAR-Landslides

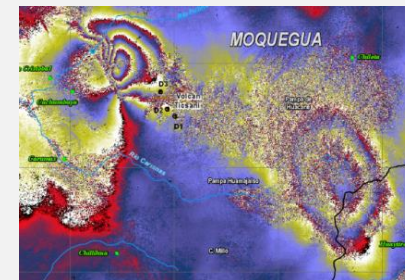


Pallata (Tacna)

INSAR-Volcanoes-Active faults



Sabancaya volcano earthquake, 16/07/2013, ML: 5.9



Ticsani volcano

RS in geological hazards mapping

INSAR-volcano monitoring

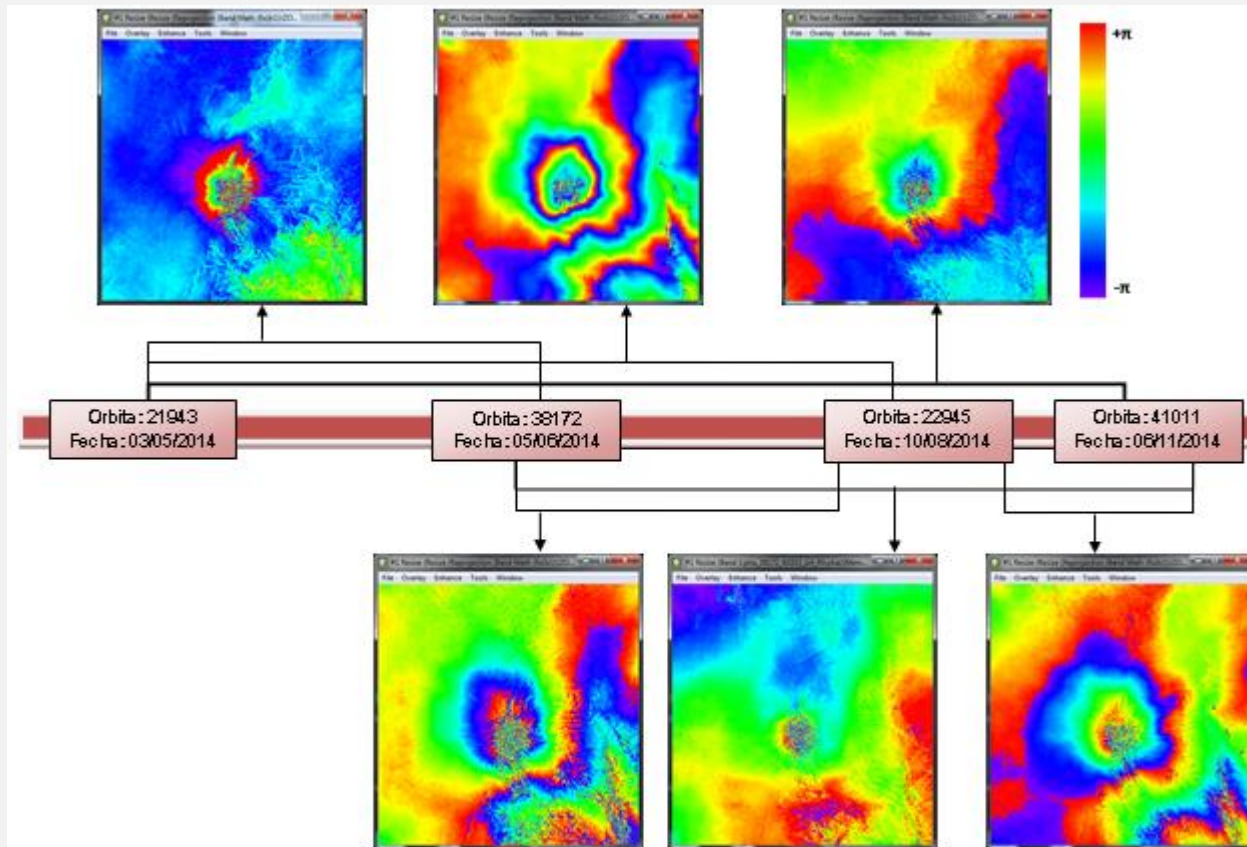
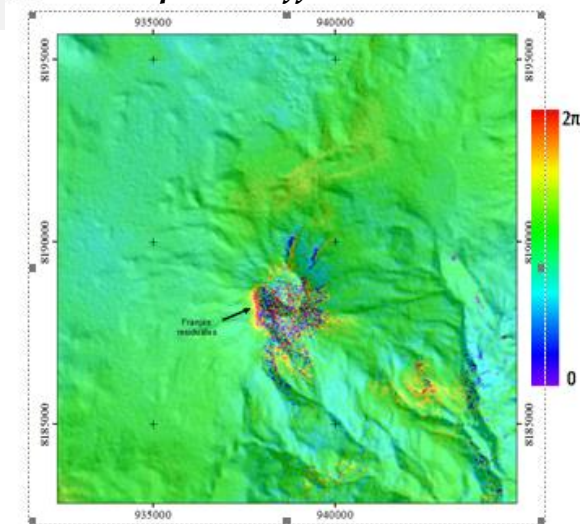


Figura 1. Interferogramas 21943_38172, 21943_22945, 21943_41011, 38172_22945, 38172_41011, 22945_41011.

Atmospheric effect removal



03/05/2014_05/06/2014



Problems with the atmospheric effects

→ Implement Permanent Scatterers INSAR technique

Content

❖ Introduction

- ✓ Remote Sensing Laboratory

❖ INGEMMET experience in using Remote Sensing

- ✓ RS in geological mapping
- ✓ **RS in mineral prospecting**
- ✓ RS in environmental impact of mining

❖ Perspectives

RS in mineral prospecting

The Mineral and Energy Resources Directorate (DRME) of INGEMMET has a permanent activity: ANAP: Prospecting of areas of non-admission of claims.

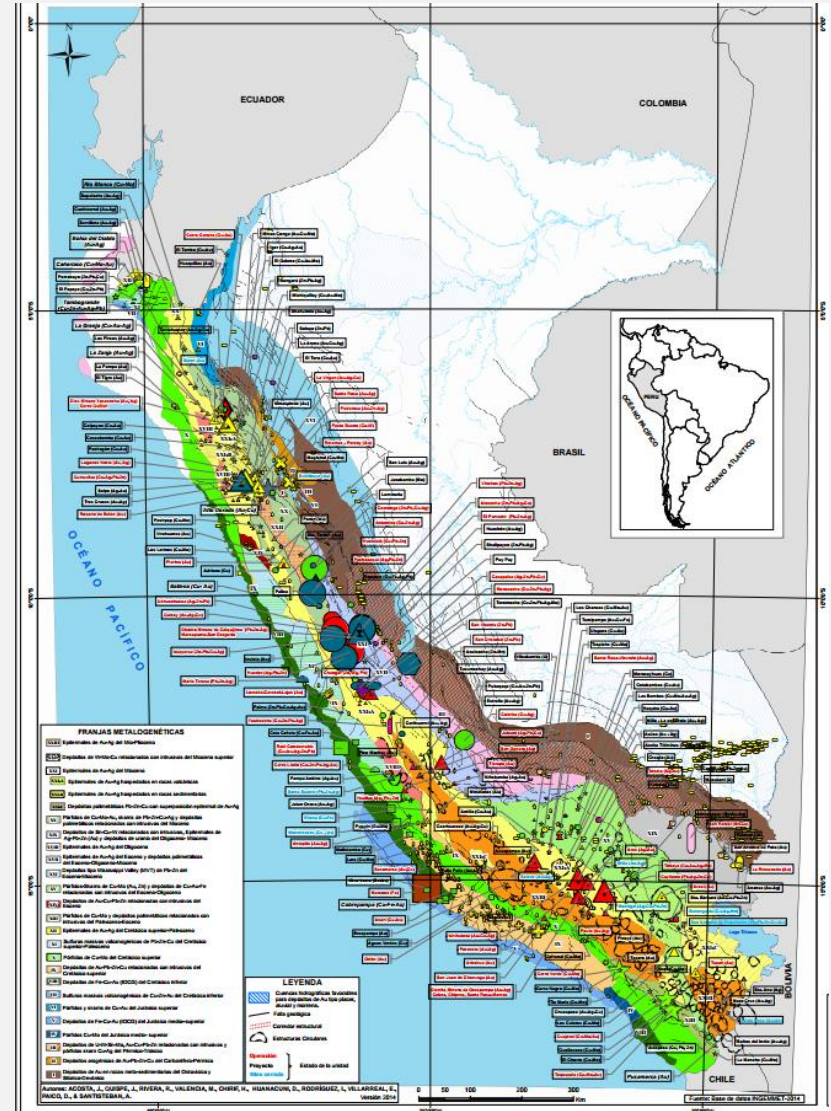
Remote sensing strategies in mineral prospecting

- The objectives of the prospecting define the working scale → satellite data type

STAGE	DESCRIPTION	COVERAGE	SCALE	SPATIAL RESOL.
		(km ²)		(m)
RECONAISSANCE	Rapid exploration over large area	5,000-20,000	Small 1:100,000	20-80
REGIONAL	Exploration within known mineral belt or trend, or individual volcanic field or mountain range	500-5000	Intermediate 1:25,000	10-30
DISTRICT	Exploration and mapping within a mining district or hydrothermal center	10-500	Big 1:10,000	6-10
DEPOSIT	Detailed mapping from early project phase to feasibility drilling	0.1-10	Very big 1:2,500	3-7

Modified from Spatz (1996)

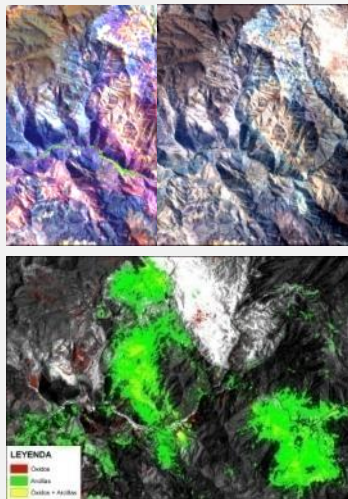
Metagenetic map - 23 metagenetic



RS in mineral prospecting

LANDSAT

Multi-spectral (30m)



RATIOS

3/1: oxides

4/3: ferric min.

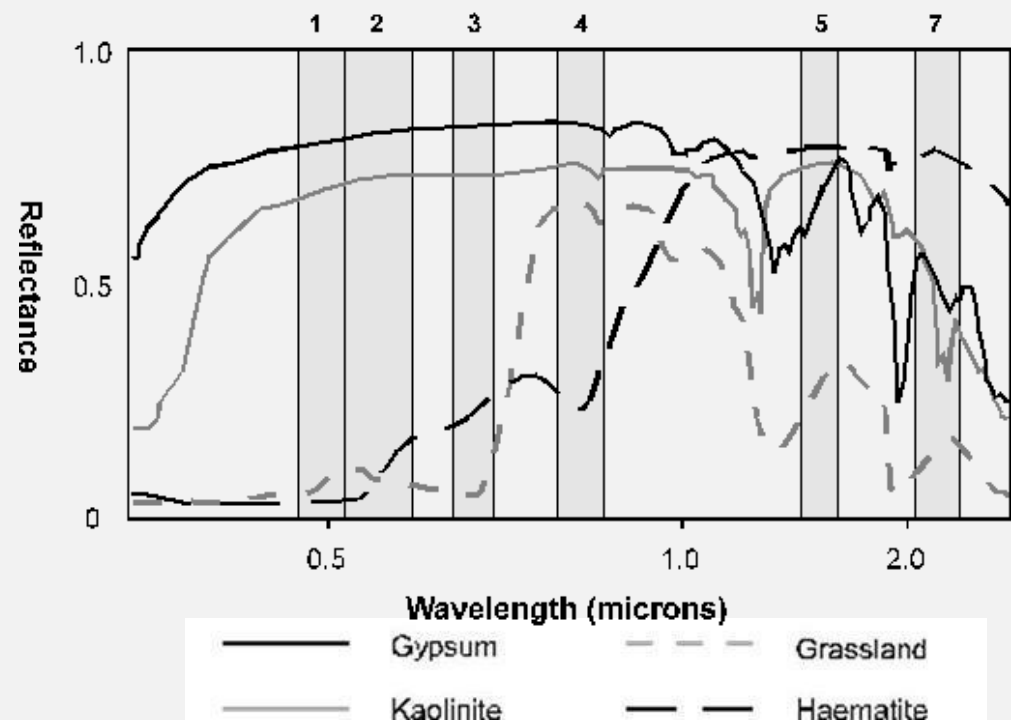
5/7: clays

PCA:

1345: oxides

3457: clays

Landsat Thematic Mapper Bands

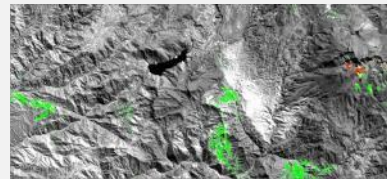


Hydrothermal alteration minerals with diagnostic spectral absorption properties in the visible and near infrared through the shortwave length infrared regions can be identified by multispectral and hyperspectral remote sensing data as a tool for the initial stages of porphyry copper and epithermal gold exploration

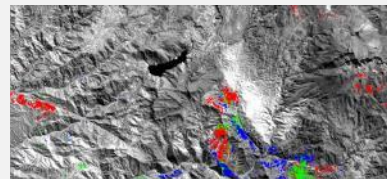
RS in mineral prospecting

ASTER

Multi-spectral (15m, 30m, 90m)



Oxides+clays

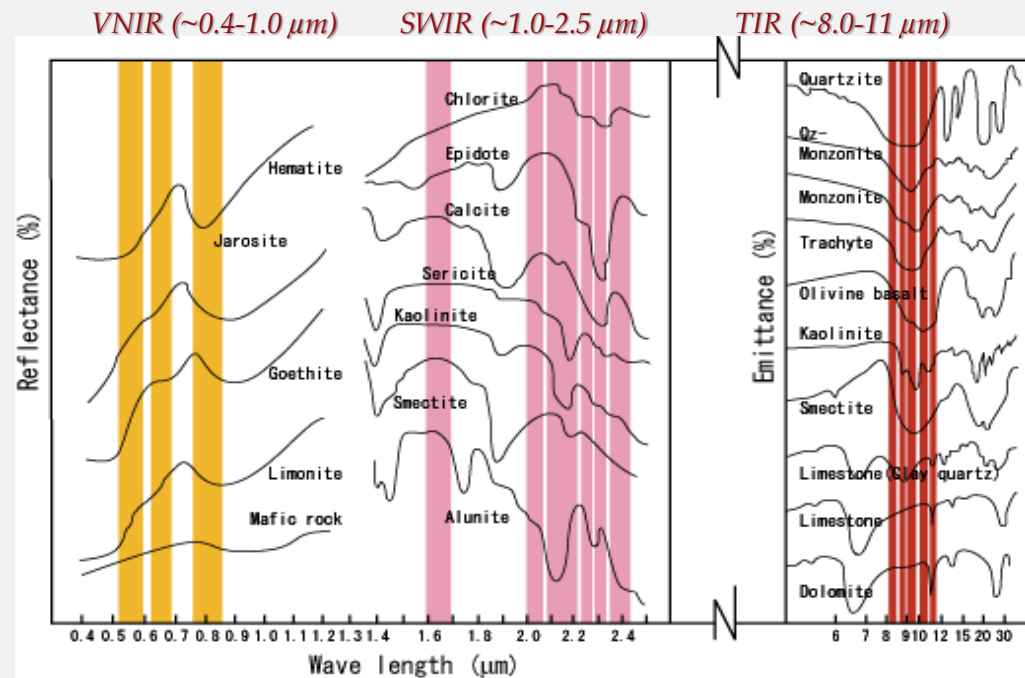


Alteration type

RATIOS
2/1: oxides
4/6: argilic alt.
5/6: a. phylic alt.
5/8: carbonates

Alteration Zone	Major + Minor Minerals
Propylitic	Epidote, chlorite, albite, carbonate, montmorillonite, goethite + K-mica, pyrite, zeolites
Argillic	Montmorillonite, kaolinite, quartz, K-mica, goethite, hematite, jarosite + chlorite, carbonate
Phyllic	Quartz, K-mica, kaolinite, smectite clays, hematite, jarosite, + K-feldspar, albite
Advanced Argillic	Quartz, pyrophyllite, alunite, kaolinite, opal, K-feldspar, K-mica, hematite + anatase
Opalized	Quartz, alunite, kaolinite, pyrophyllite, calcite + anatase
Silicified	Quartz, alunite, kaolinite, diaspore, pyrophyllite, hematite, goethite, jarosite + anatase, rutile, opal, K-mica

After Rowan and Latham, 1980



Mineral classification

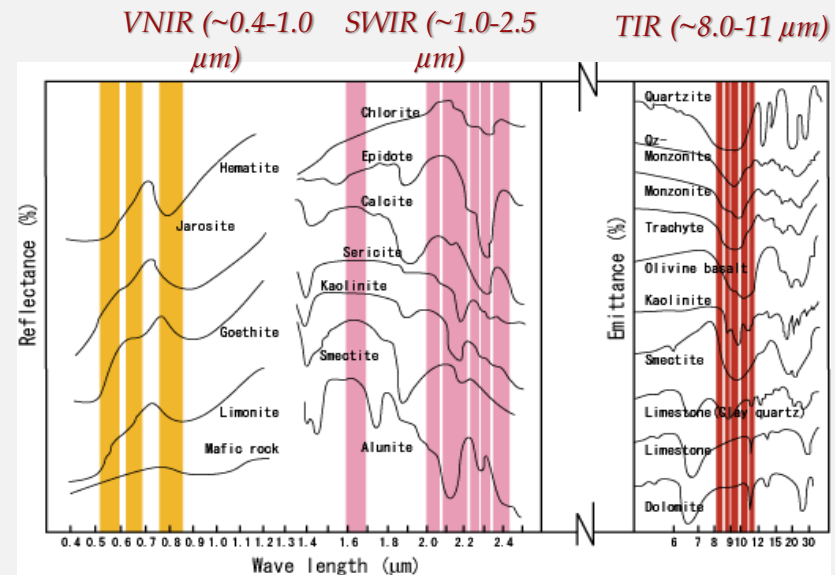
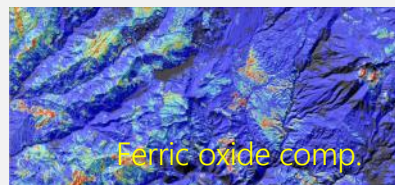
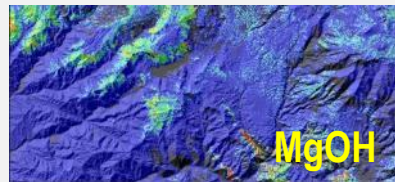
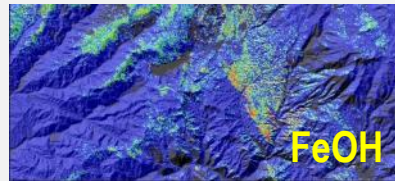
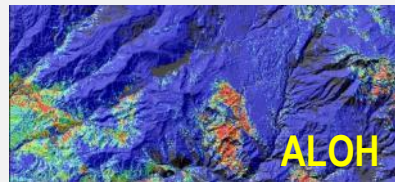
-> **limited**

RS in mineral prospecting

ASTER

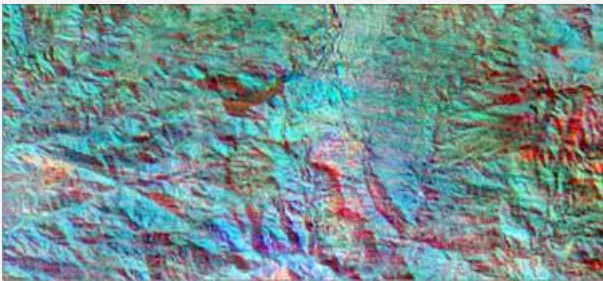
Multi-spectral (15m, 30m, 90m)

Maps content using Al-OH, Fe, Mg-OH, H-O-H, and CO₃ absorption features



RS in mineral prospecting

ASTER



MAPA RGB:QI, CI, MI

Multi-spectral (15m, 30m, 90m)

Maps content using Al-OH, Fe,Mg-OH, H-O-H, and CO₃ absorption features

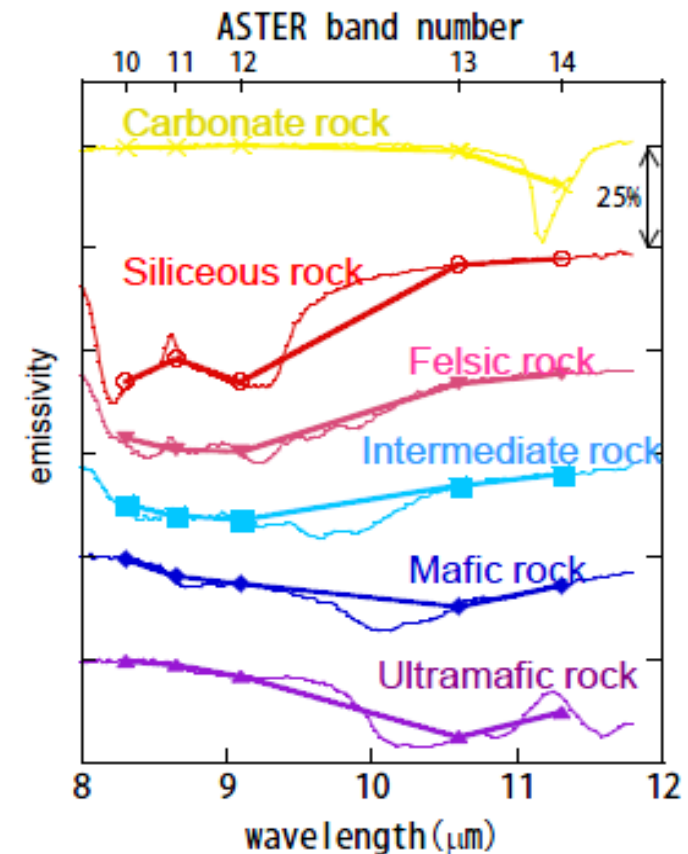
Carbonate Index $CI = \frac{D_{13}}{D_{14}}$

Quartz Index $QI = \frac{D_{11} \times D_{11}}{D_{10} \times D_{12}}$

(Mafic Index $MI = \frac{D_{12}}{D_{13}}$)

Improved Mafic Index $MI_3 = \frac{SI^-}{CI^3}$

Fuente:
Ninomiya and Fu, 20012



RS in mineral prospecting

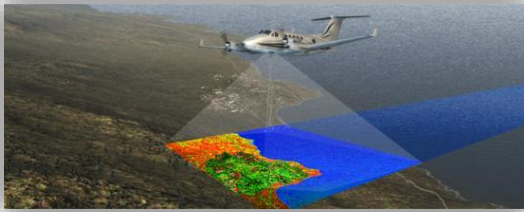
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Modified from Spatz (1996)

HIPERSPECTRAL RS in mineral prospecting

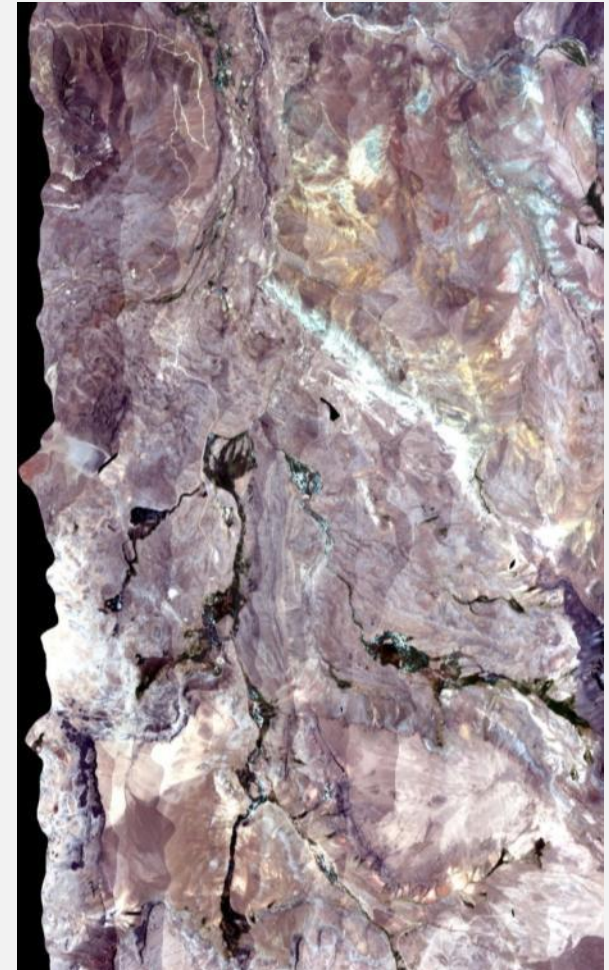
- ❖ First INGEMMET experience using hyperspectral imagery for mineral prospecting.
- ❖ October 2014, flights performed by SPECTIR Inc. in Moquegua department, south Peru.



Hyperspectral sensor AISA DUAL (EAGLE+HAWK), SPECIM.

Spectral range	Spectral resolution	N° of bands	Spatial resolution	Vision angle
VNIR: 400-970nm SWIR: 970-2500nm	VNIR: 3.3nm SWIR: 12nm	360	1 – 10 meters (→ flight altitud)	VNIR: 37.7° SWIR: 35.5°

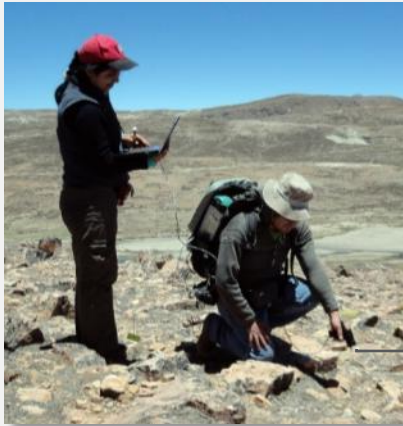
- ❖ Objective → ANAP (Area de No Admisión de Petitorio) prospecting



AISA DUAL mosaic

HIPERSPECTRAL RS in mineral prospecting

Fieldwork for hyperspectral groundtruthing



Field measurements using spectroradiometer FieldSpec 4

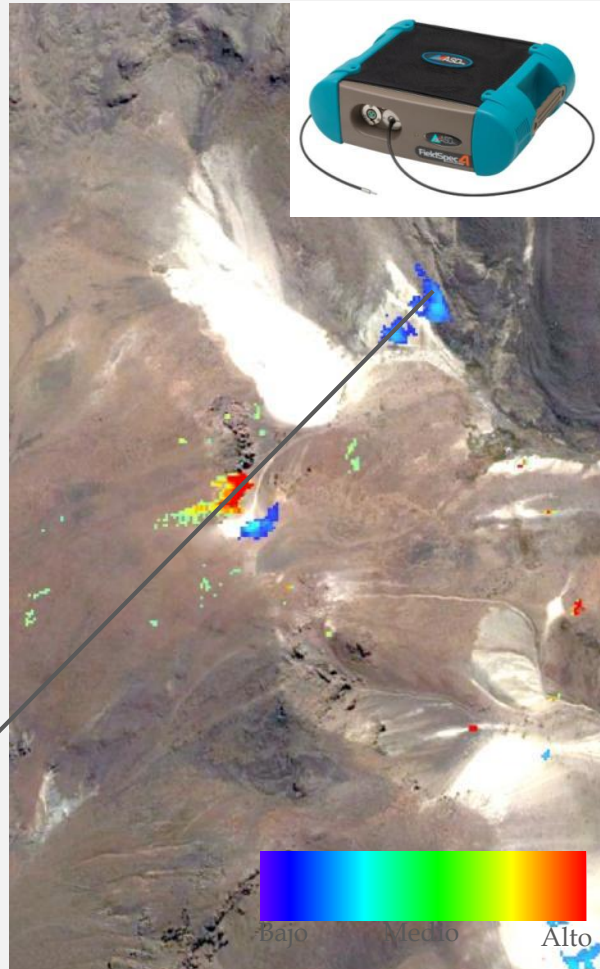
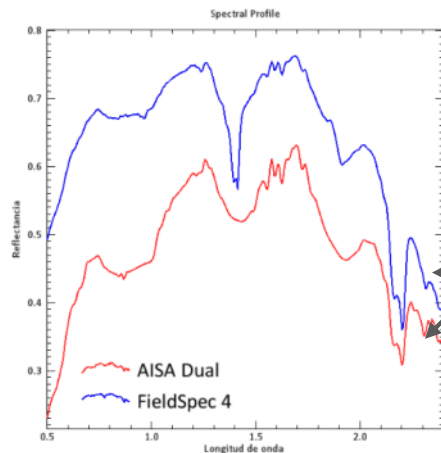


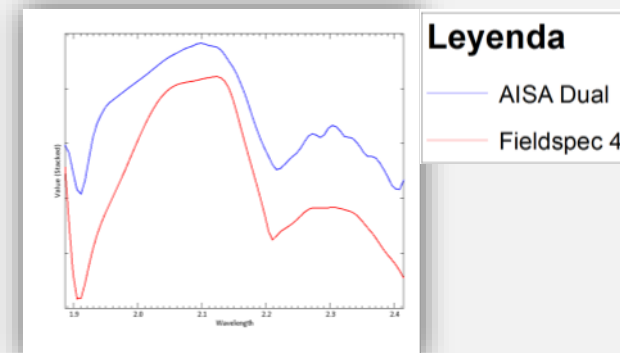
Imagen Hiperspectral AISA Dual



Laboratory measurements using spectroradiometer FieldSpec 4

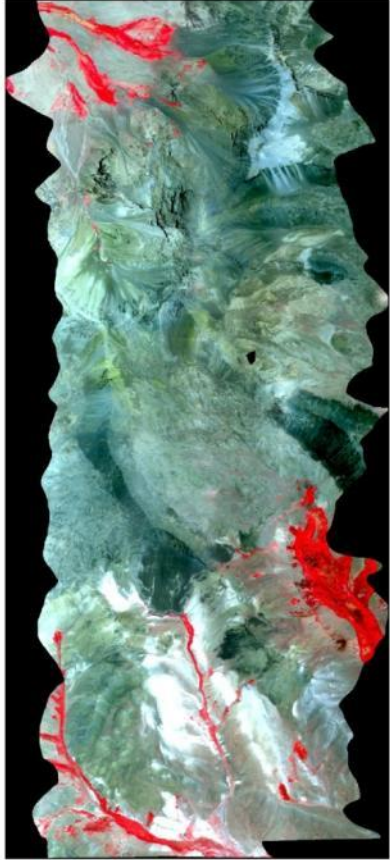


3*3 m average pixel radiometric measurement

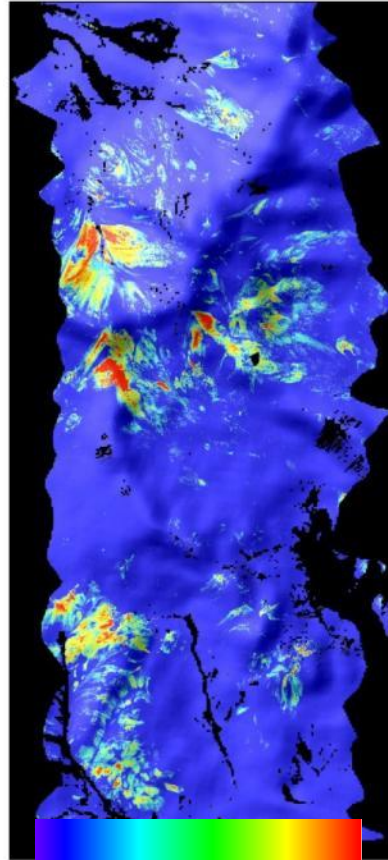


HIPERSPECTRAL RS in mineral prospecting

Hyperspectral AISA DUAL



RGB: 100, 56, 35



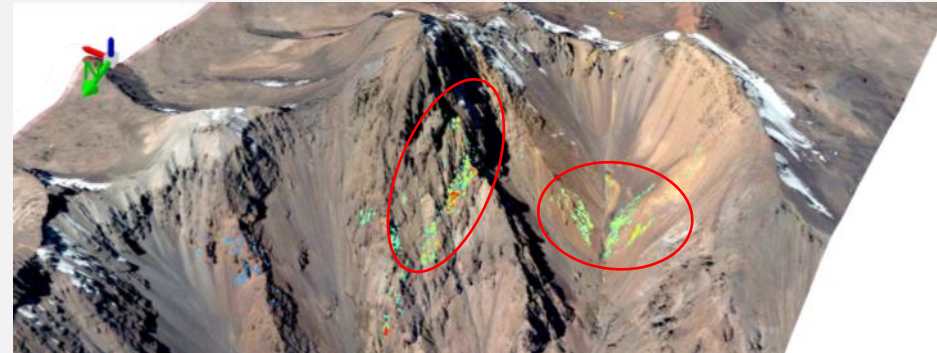
Bajo Medio Alto

$$\text{Fe oxide abundance} = \frac{0.761\mu\text{m}+1.190\mu\text{m}}{0.886\mu\text{m}+0.919\mu\text{m}}$$

Mineral clasification



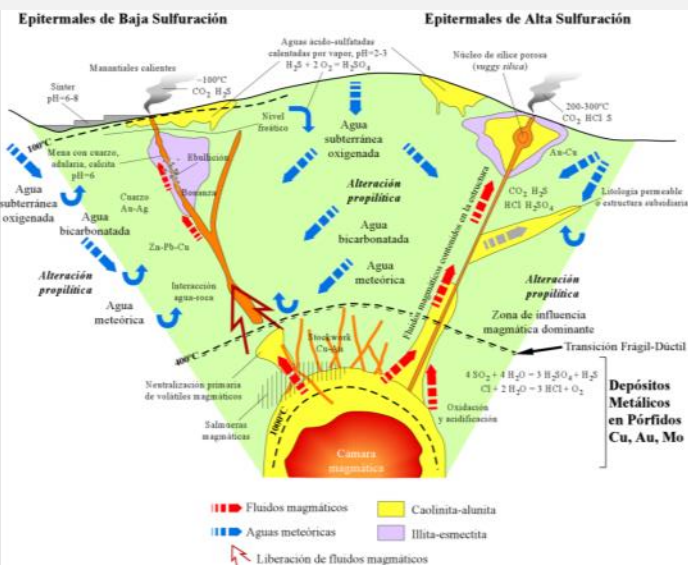
Hematite – Goethite



RS as a tool for mineral prospecting

❖ Spectral ranges for geology-mining applications

Esquema de la estructura de procesos, tipos de alteración, temperaturas, ph, tipo de fluidos, y reacciones en la formación de depósitos epitermales de alta y baja sulfuración (Camprubi et al., 2003).



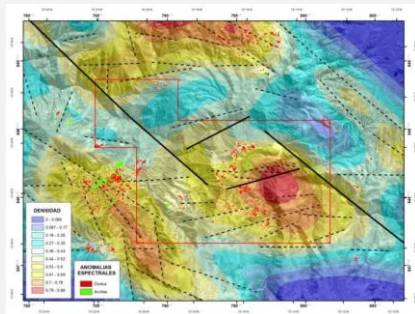
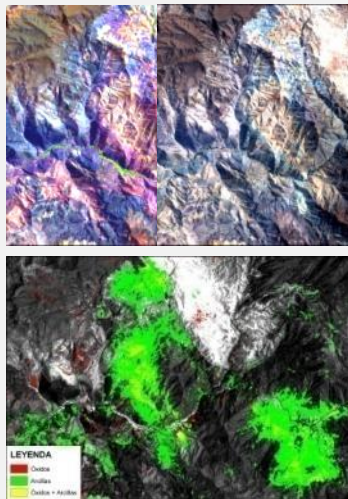
	MULTIESPECTRAL	----->	HIPERESPECTRAL
400	Excavaciones, caminos		
500	Vegetación		
600	óxidos de hierro		
	Formaciones ferruginosas		
700		Vegetación	Red edge shift
			Red edge shift
			Red edge shift
800			Hematita
900	Óxidos de hierro		Jarosita
			Gohetita
1000			
CAMBIO DE ESCALA			
1400		Jarosita	
		Óxidos de hierro	
1500	Rocas leucocráticas		
1600	Tonos claros vs. Oscuros		
1700			
1800			
1900			
2000		Sulfatos	Yeso
		Silicatos de amonio	Budingtonita
CAMBIO DE ESCALA			
2100	Silicatos hidróxilo	Minerales sulfatados ácidos	Pirofilita
			Alunita
2200	Carbonatos	Mineral argílico-fílico	Sericita
			Illita
			Caolinita/Dickita
			Montmorillonita
			Silice amorfa
2300	Sulfatos	Mineral propilitica	Calcita
			Epidota
			Clorita
2400		Fuente: Modificado de Spatz (1996)	

RS in mineral prospecting

Multi-spectral

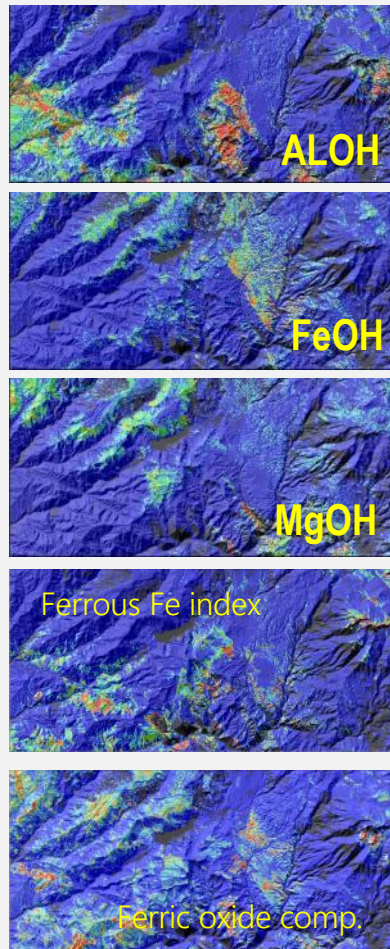
Hyperspectral

LANDSAT

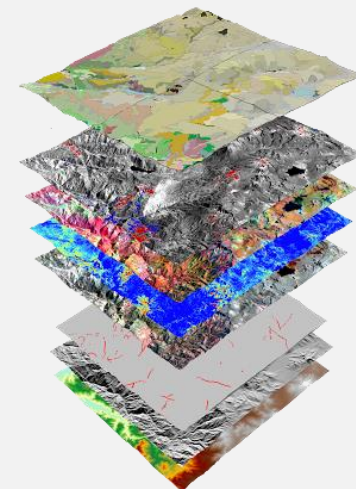
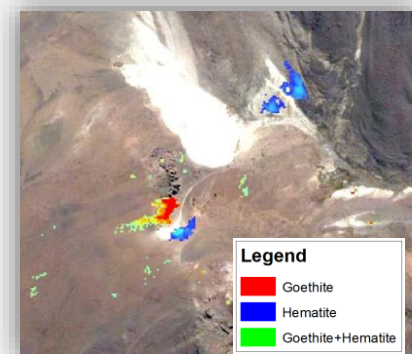


Faults density

ASTER



AISA DUAL



Multi-layer
analysis

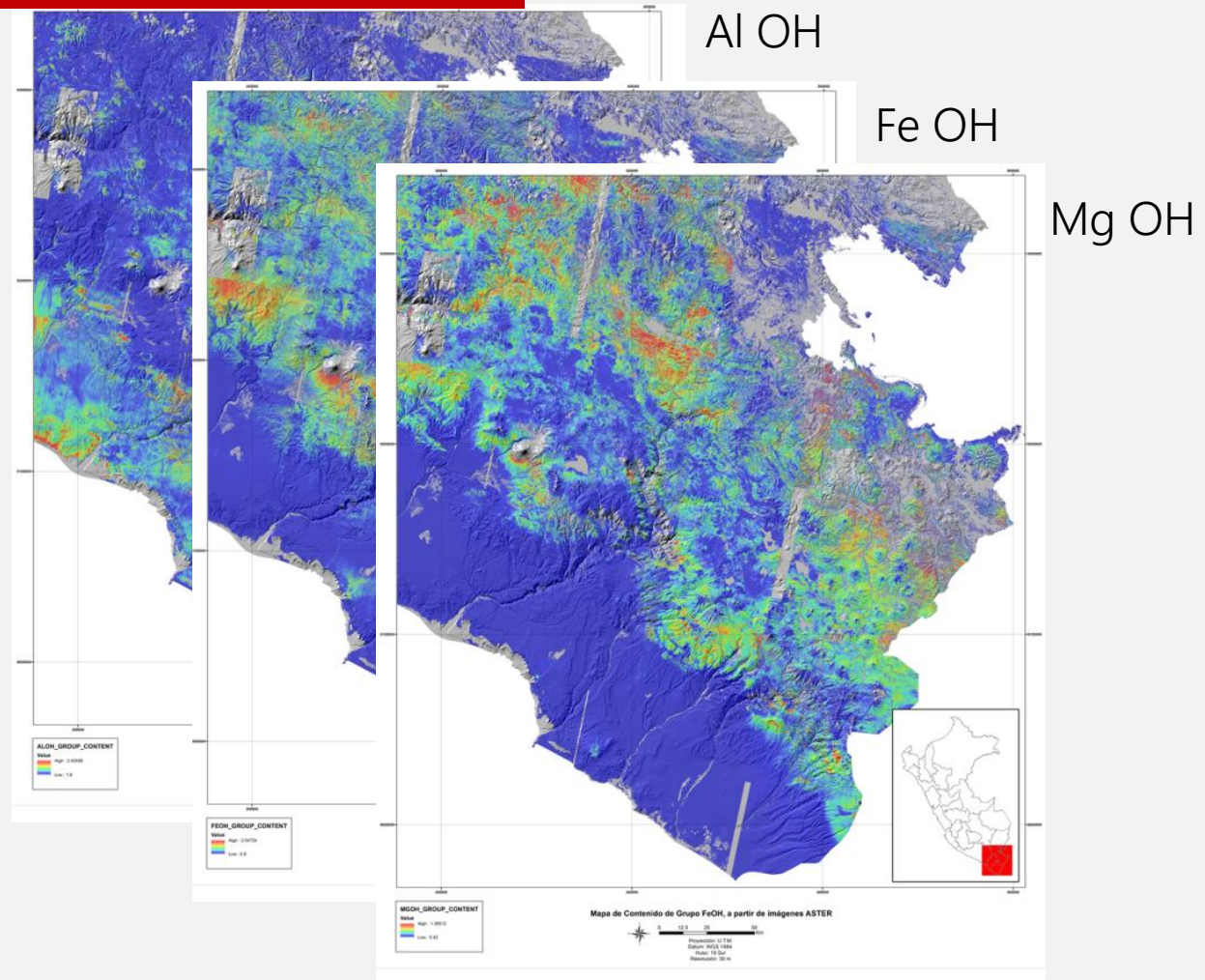
RS in mineral prospecting

ASTER products to improve resource prospecting

Based on ASTER geoscience products of Australia methodology (By Geoscience Australia, the Commonwealth Scientific Research Organisation (CSIRO) and state and industry partners). Products are a combination of bands and band ratios to highlight different mineral groups.



Problems with radiometric normalization in multiple ASTER images mosaic
→ caused by seasonal acquisitions time.

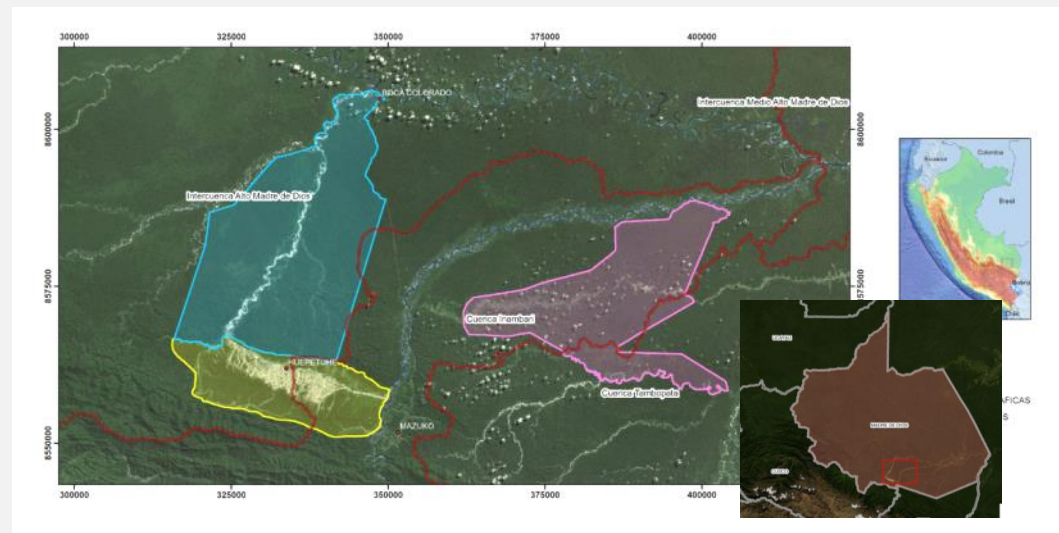


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 - ✓ RS in environmental impact of mining
- ❖ Perspectives

RS in mining environmental impact assesing

Illegal mining activities in Madre de Dios-Expansion Monitoring

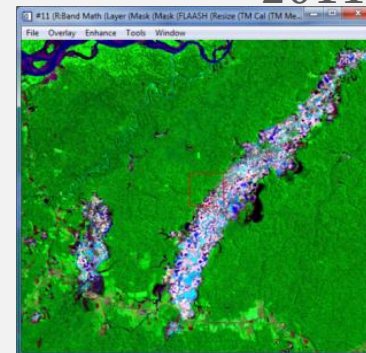
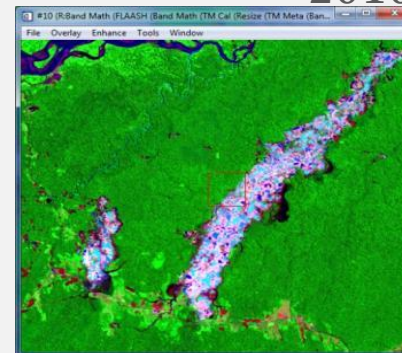
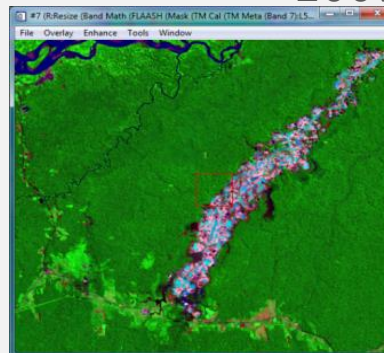
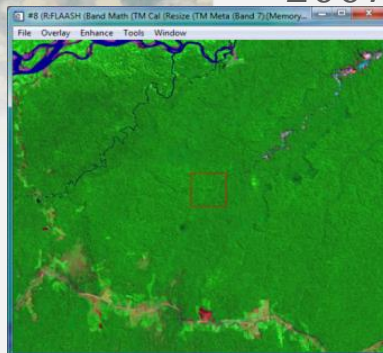


2007

2009

2010

2011



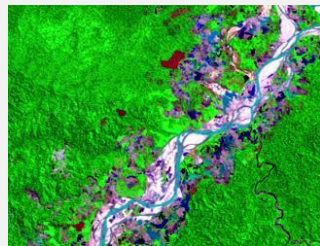
LANDSAT
7 temporal
serie

RS in mining environmental impact assesing

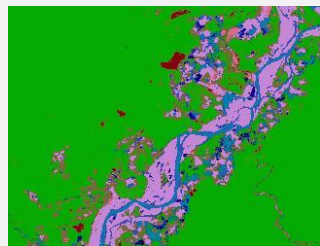
Fieldwork for validate classifications

Date: 2011

- ✓ Colección de librerías espectrales con espectrómetro FieldSpec Hi-Res.
- ✓ Análisis espectral



LANDSAT
RGB:742

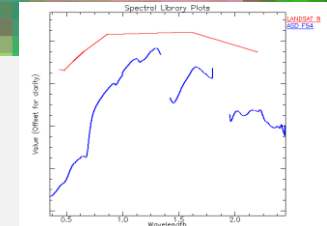
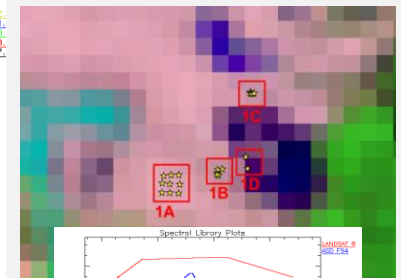
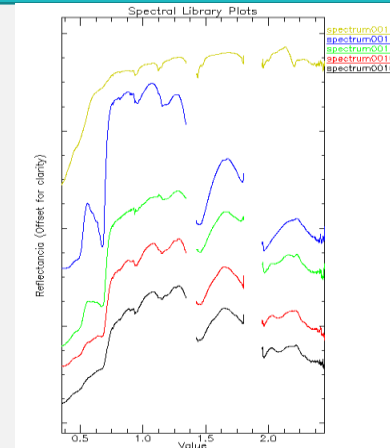
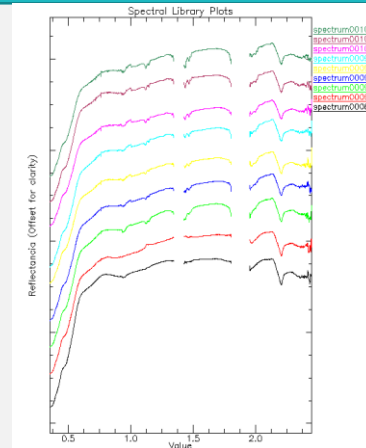


SAM
(Spectral Angle
Mapper)
classification



Post -
Classification

- Clases**
- VEGETACIÓN
 - AGUA CON TURBIDEZ ELEVADA
 - EMPOZAMIENTO DE AGUA/LODO POR MINERÍA
 - PLAYA
 - MINERÍA (REMOCIÓN DE GRAVAS)
 - MINERÍA EN PROCESO DE RECUPERACIÓN



RS in mining environmental impact assesing

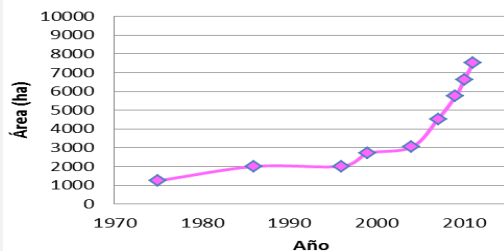
Imagen LANDSAT
RGB:674 (Año: 1975)



Imagen LANDSAT
RGB:674 (Año: 2011)



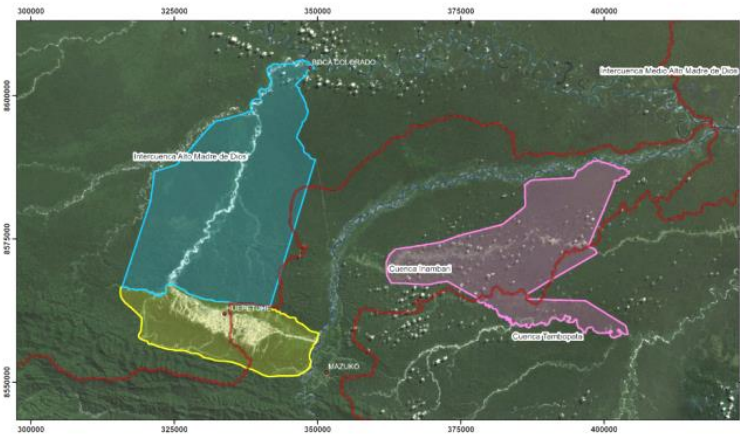
Madre de Dios



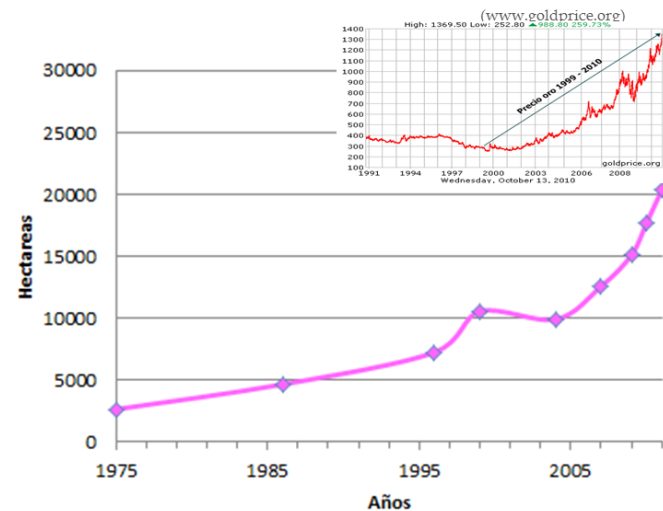
Área : 84,150 ha

2011: área afectada 7,500 ha

En 4 años → aprox. 750 ha / año



Áreas afectadas por la actividad minera

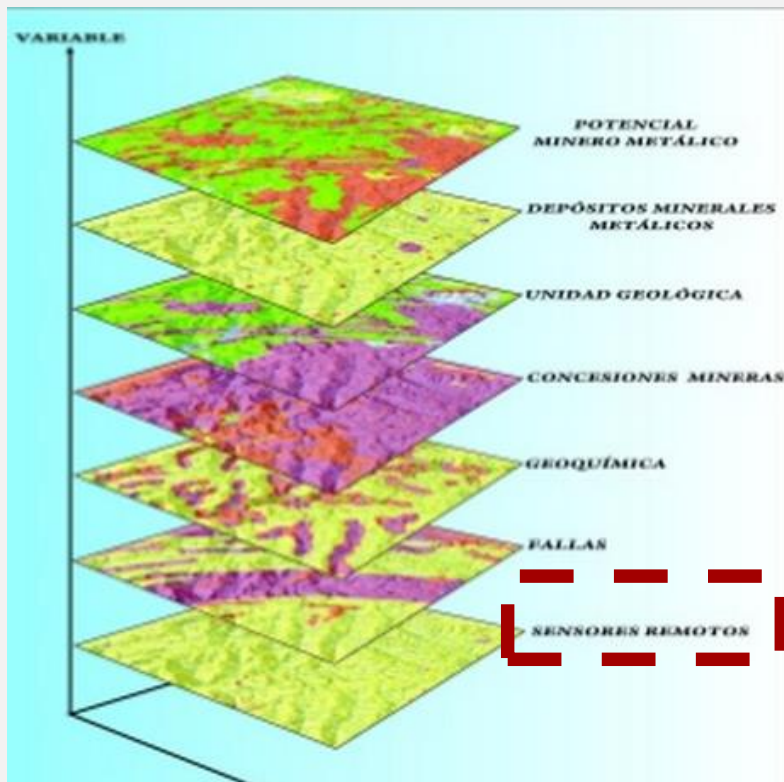


Content

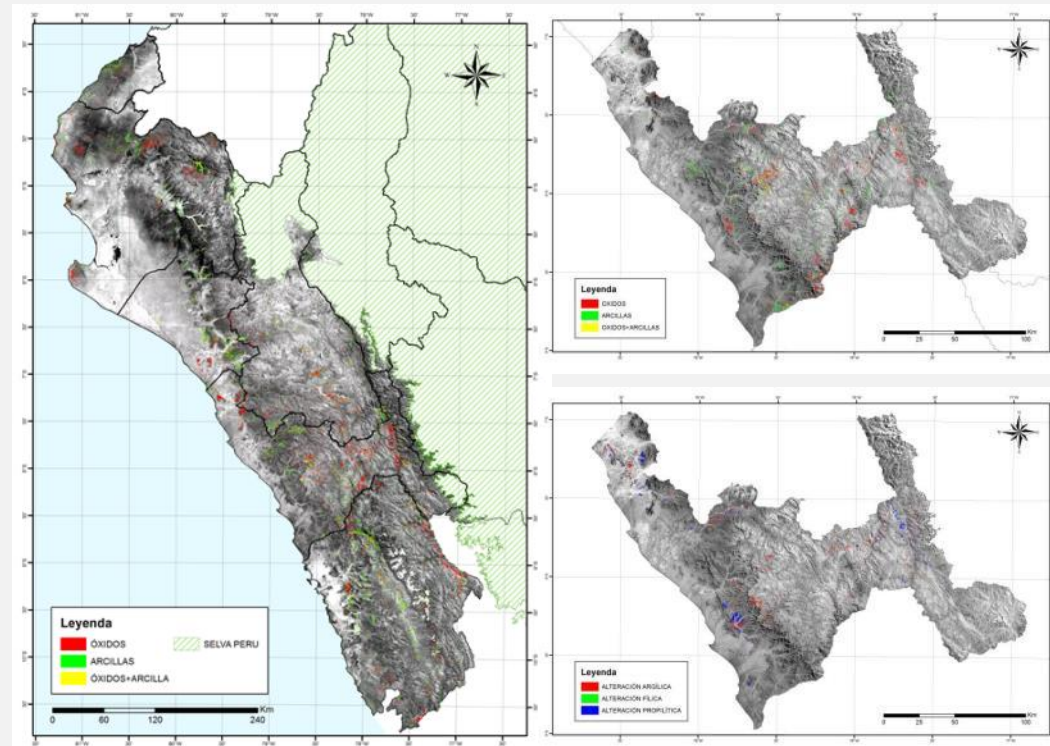
- ❖ Introduction
 - ✓ Remote Sensing Laboratory
- ❖ INGEMMET experience in using Remote Sensing
 - ✓ RS in geological mapping
 - ✓ RS in mineral prospecting
 - ✓ RS in environmental impact of mining
- ❖ Perspectives and needs

RS in mineral prospecting

- ❖ Current activities in INGEMMET to estimate mineral potential and EEZ
Remote sensing layer is used as input to estimate mineral potential.



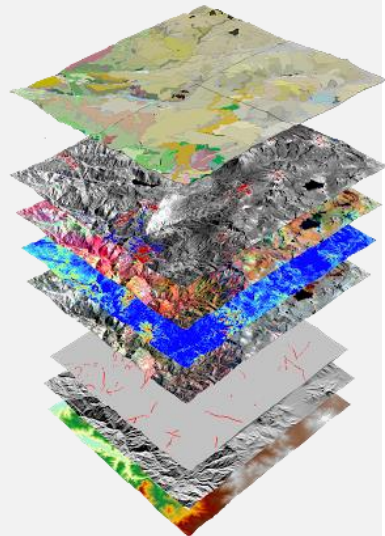
Source: Manual de evaluación de recursos y potencial minero en Perú, INGEMMET



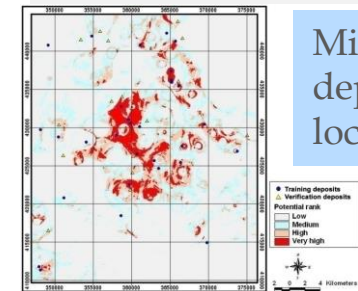
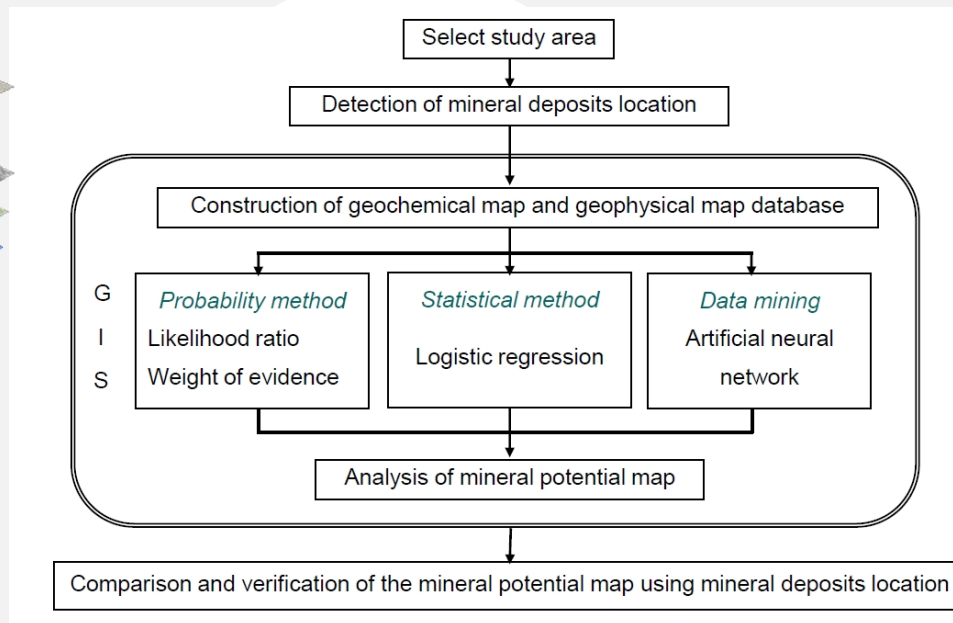
RS in mineral prospecting

Statistical methods and GIS modelling to estimate probability of occurrence of events (like mineral deposits, landslides, etc.)

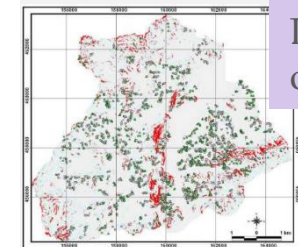
Regresión logística



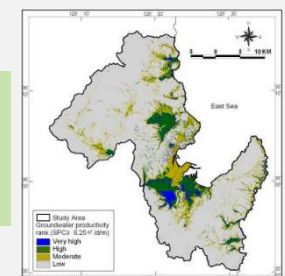
Independent data



Mineral deposit location



Landslides occurrence



Underwater occurrence probability

 Application of statistical methods and GIS modelling in order to estimate mineral deposit locations

Thank you

