BHARATHIDASAN UNIVERSITY

Tiruchirappalli- 620024
Tamil Nadu, India

Programme : M.Tech., Geological Technology and Geoinformatics

Course Title : Geoinformatics in Disaster Management
Course Code : MTIGT0704

Unit-5: Other Geohazards

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Unit-5: Other Geohazards - Volcanic hazards: Nature of volcanic hazards, Factors determine violence of volcanic eruption - volcano exclusivity index - role of remote sensing in prediction and fore warning of volcanic eruption. Glacial: Types of glacial hazards - Remote Sensing and GIS in glacial hazards mapping and mitigation- Formation and types of Cyclones – forewarning of cyclone – Geoinformatics in cylone prediction and management studies .

Geoinformatics in Volcanic Disaster

An artist's rendition of the volcanic eruption on Thera that destroyed most of the island in about 1390 BC. Most of the island's inhabitants escaped the devastation

When Mt. Vesuvius erupted in A.D. 79, the people in nearby Pompeii were trapped and suffocated beneath a layer of volcanic ash up to 8 m thick. When Pompeii was excavated, archaeologists found cavities lines with an exact imprint of the decomposed bodies: by pouring plaster into the cavities they were able to make casts that displayed the victim’s musculature, agonized facial expressions and in some cases even the folds in their clothing.

A VOLCANO is a vent in earth's crust through which molten rock, steam, gas, and ash are expelled

volcano: **opening in Earth's crust through which molten rock, gases, & ash erupt to the land around the opening**

Volcanoes is the Windows of Earth's interior

- ❑ **Help us understand plate tectonic process and mantle convection**
  - ❖ ***At present, but also millions to billions of years in past using radioisotopic dating***
- ❑ **Impact Earth's atmosphere and hydrosphere**
- ❑ **Pose hazards to millions of people**
- ❑ **Geothermal energy sources**

  Regions near hot springs and geysers have hot water that can be tapped and used to drive turbines to generate electricity.

Volcanism and human affairs

Hazards

- Pyroclastic flow
- Lava flows
- Ash flows
- Lahars
- Volcanic gas
- Flank collapse
- Caldera collapse
- Eruption clouds
- Acid rains
- Landslides
- Seismicities
- Tsunami

Resources

- Volcanic soils
- Industrial materials
- Ore formation
- Geothermal energy

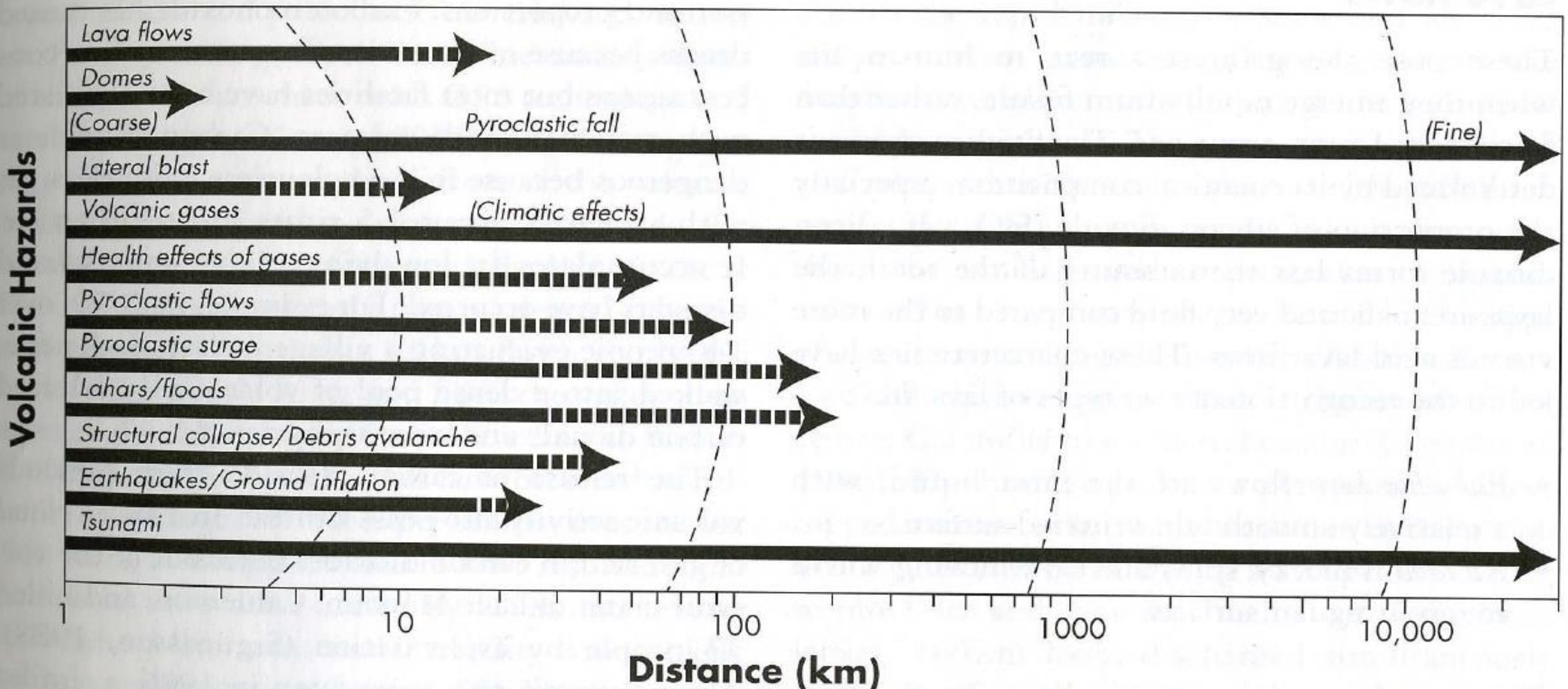


Figure 6.2 The influence of distance on destructive volcanic phenomena. Most hazards are restricted to a 10 km radius of the volcano but the effects of fine ash, gases and tsunami waves can extend beyond 10,000 km.
Source: After Chester *et al*. (2001). Reprinted from *Environmental Hazards* 2. Chester *et al*., The increasing exposure of cities to the effects of volcanic eruptions, copyright (2001), with permission from Elsevier.

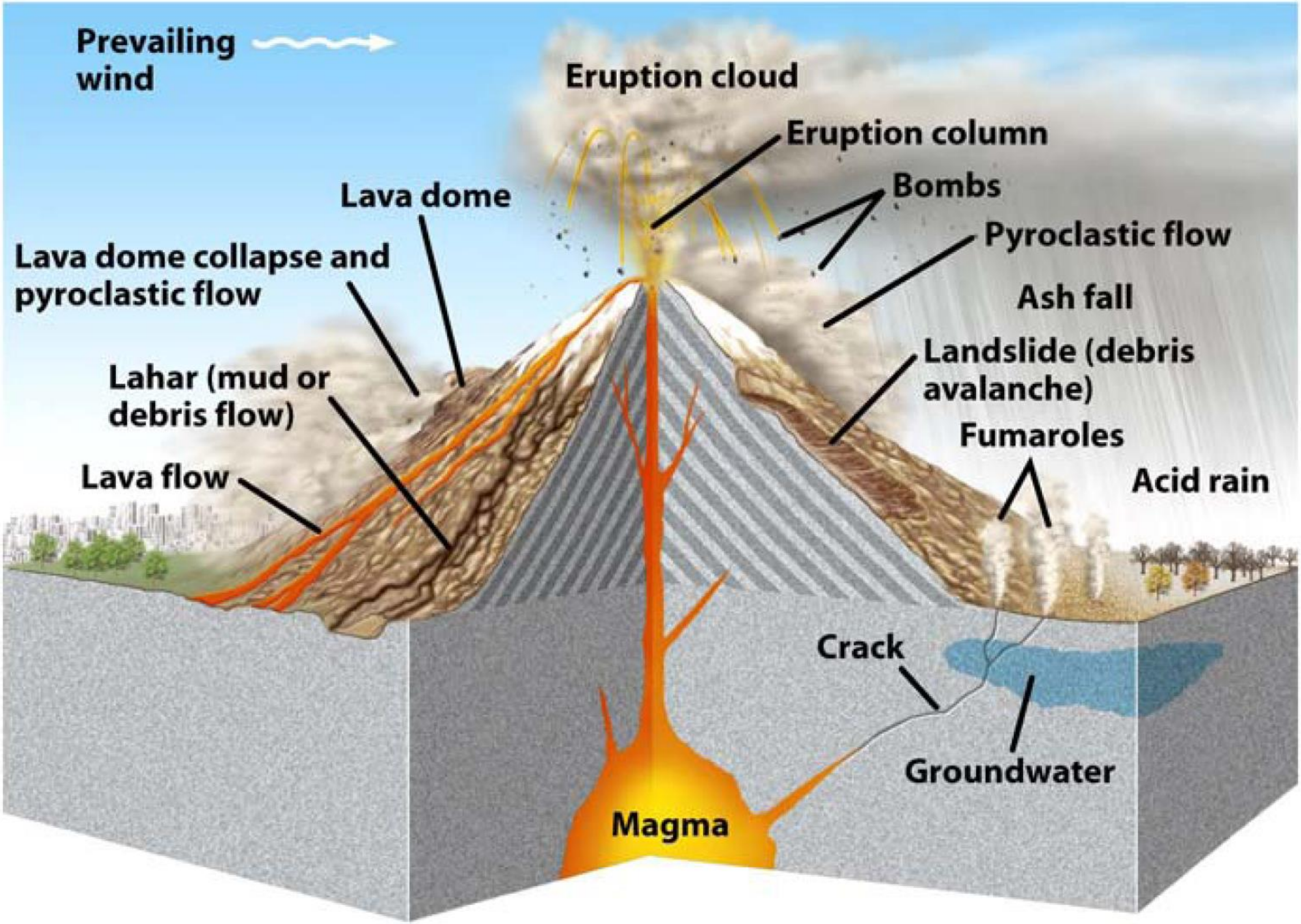
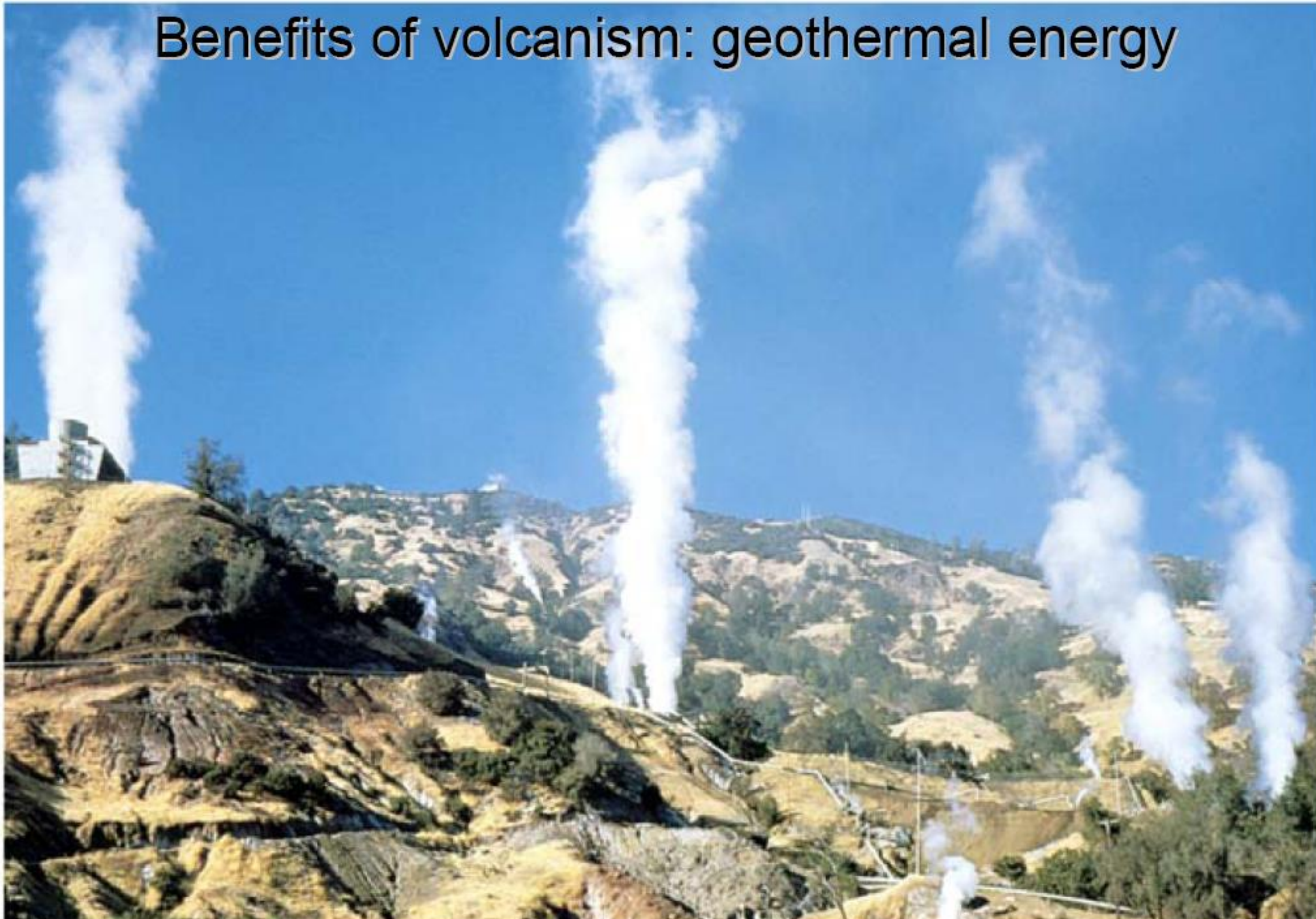


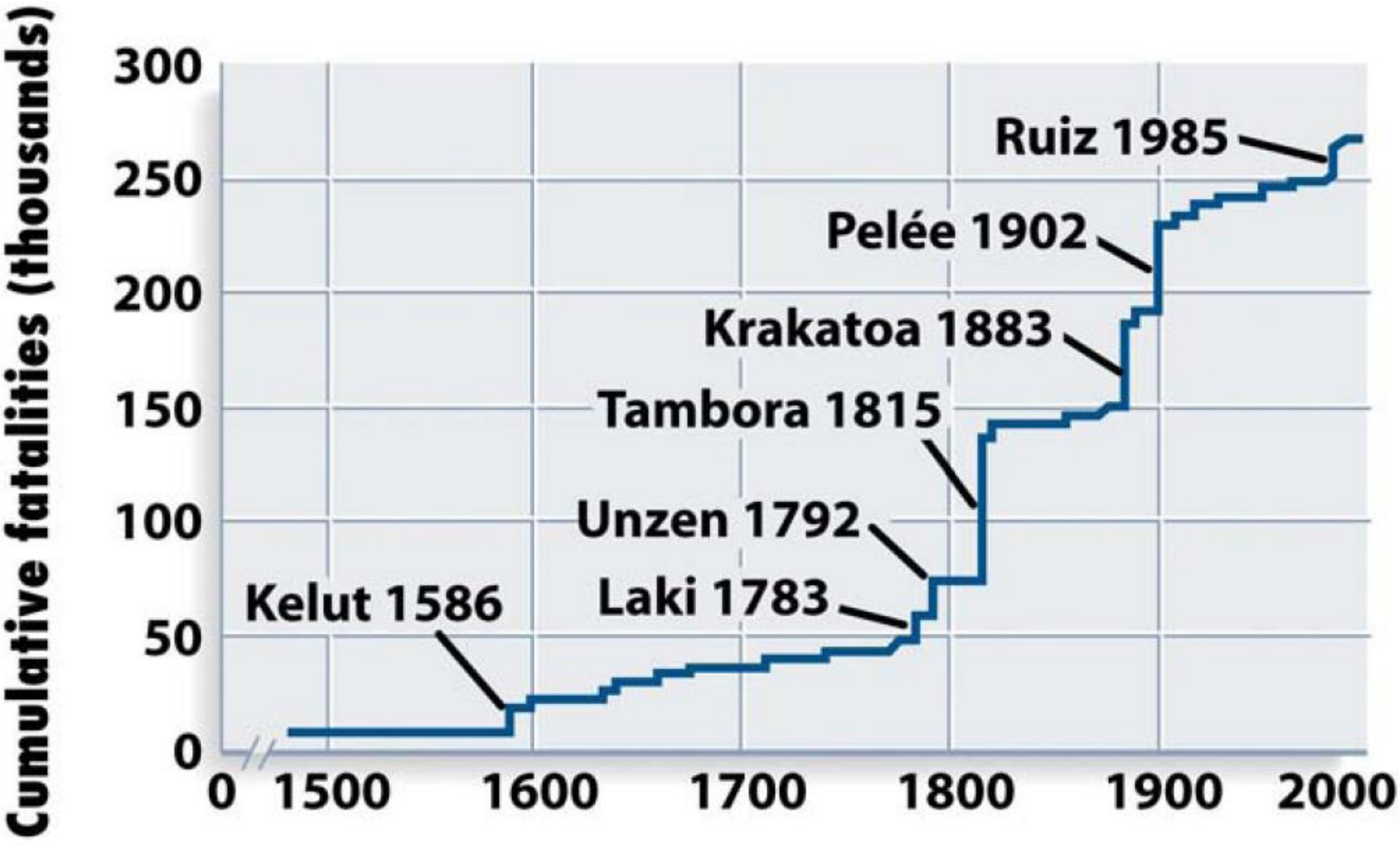
Figure 12-25
Understanding Earth, Fifth Edition

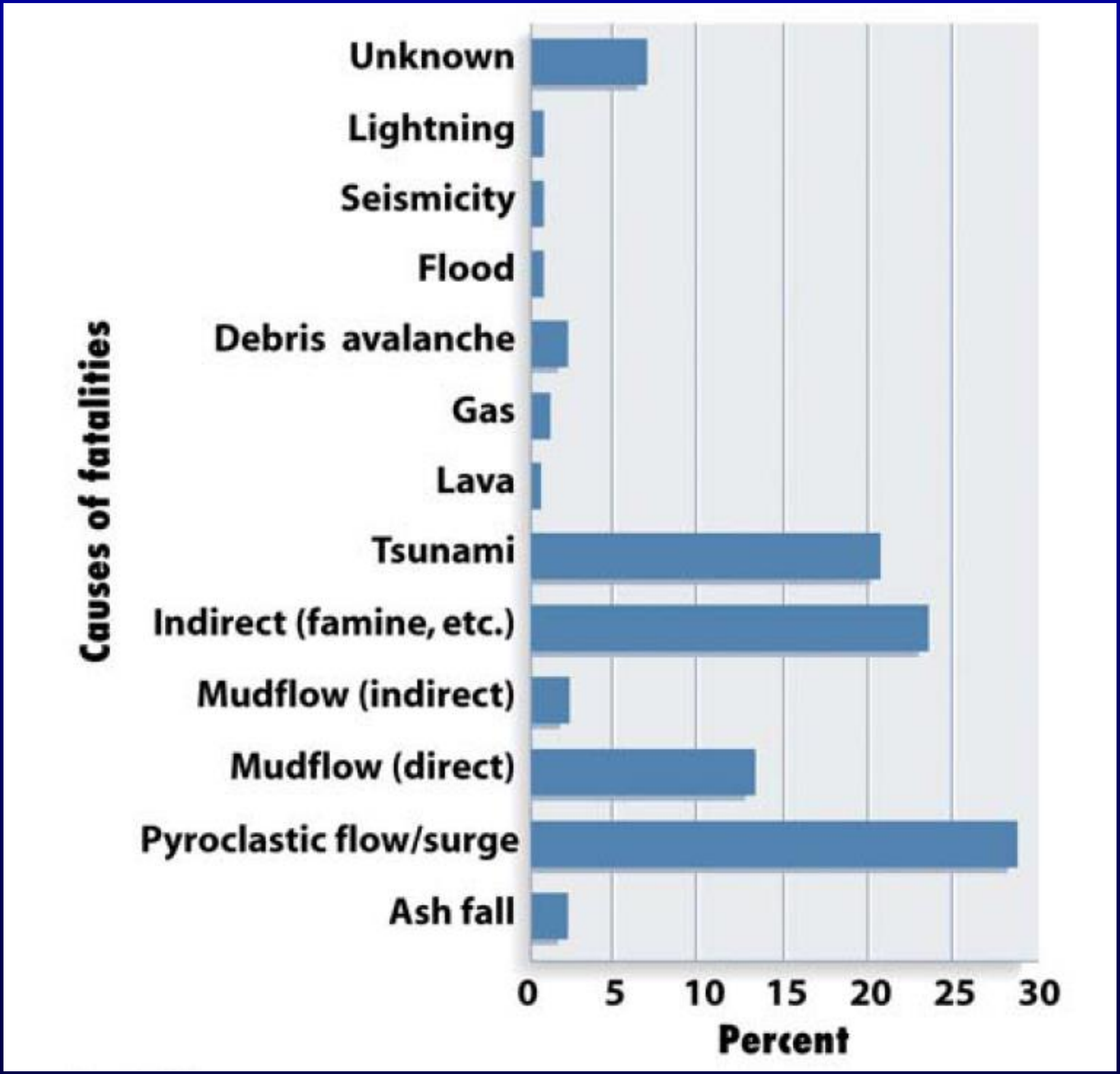
Volcanic Hazards

Benefits of volcanism: geothermal energy



Volcanism and human affairs




Unknown
Lightning
Seismicity
Flood
Debris avalanche
Gas
Lava
Tsunami
Indirect (famine, etc.)
Mudflow (indirect)
Mudflow (direct)
Pyroclastic flow/surge
Ash fall
Causes of fatalities
0
5
10
15
20
25
30
Percent

Factors that determine the violence of an eruption and viscosity

- Composition of the magma
- Temperature of the magma
- Dissolved gases in the magma

Viscosity of magma

- Viscosity is a measure of a material's resistance to flow

- **Factors affecting viscosity**
  - Temperature (hotter magmas are less viscous)
  - Composition (silica content)
    - High silica – high viscosity (e.g., rhyolitic lava)
    - Low silica – more fluid (e.g., basaltic lava)
- **Dissolved gases (volatiles)** (Provide the force to extrude lava, Violence of an eruption is related to how easily gases escape from magma)
  - Mainly water vapor, Sulper, and carbon dioxide
  - Gases expand near the surface

Quiet vs. violent activity

- Quiet eruptions tend to produce **lava flows**, which are not so dangerous
- Explosive eruptions produce fragmental, or **pyroclastic**, material; these are dangerous

- Two controls on explosivity are (1) the **silica content** and (2) the **gas content** of the magma
- **Basalt:** 50% SiO_2, gas-poor
- **Andesite:** 60% SiO_2, gas-rich
- **Rhyolite:** 70% SiO_2, gas-rich
- Magmas with higher silica contents are more viscous

Magma & Erupted Materials

Differences in volcanic activity result partly from differences in magma

SUMMARY Characteristics of Magma

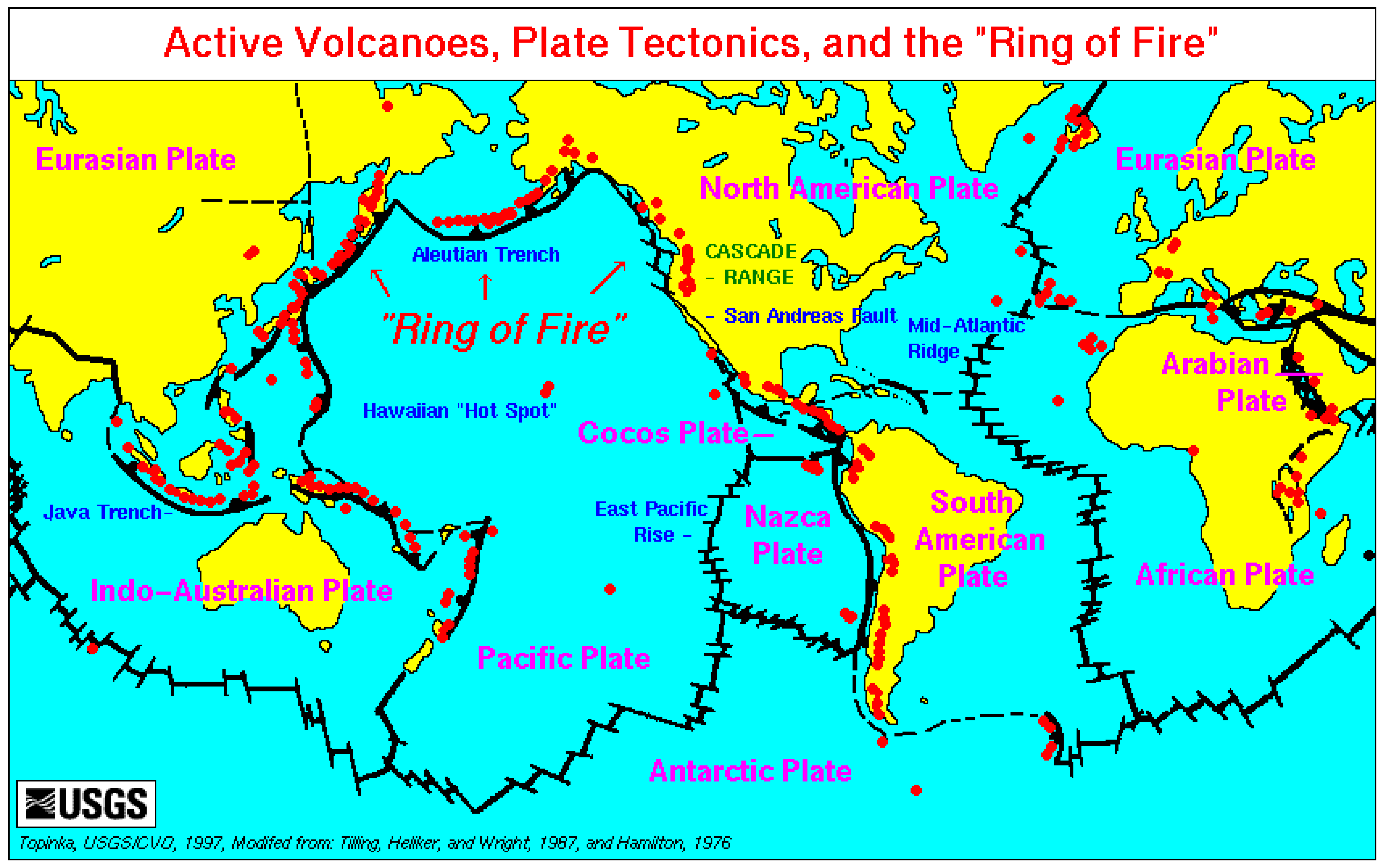
	Basaltic Magma	Andesitic Magma	Rhyolitic Magma
Silica content	Least (about 50%)	Intermediate (about 60%)	Most (about 70%)
Gas content	Least	Intermediate	Most
Viscosity	Least viscous	Intermediate	Most viscous
Type of eruption	Rarely explosive	Sometimes explosive	Usually explosive
Melting temperature	Highest	Intermediate	Lowest
Location	Rifts, oceanic hot spots	Subduction boundaries	Continental hot spots

Kilauea

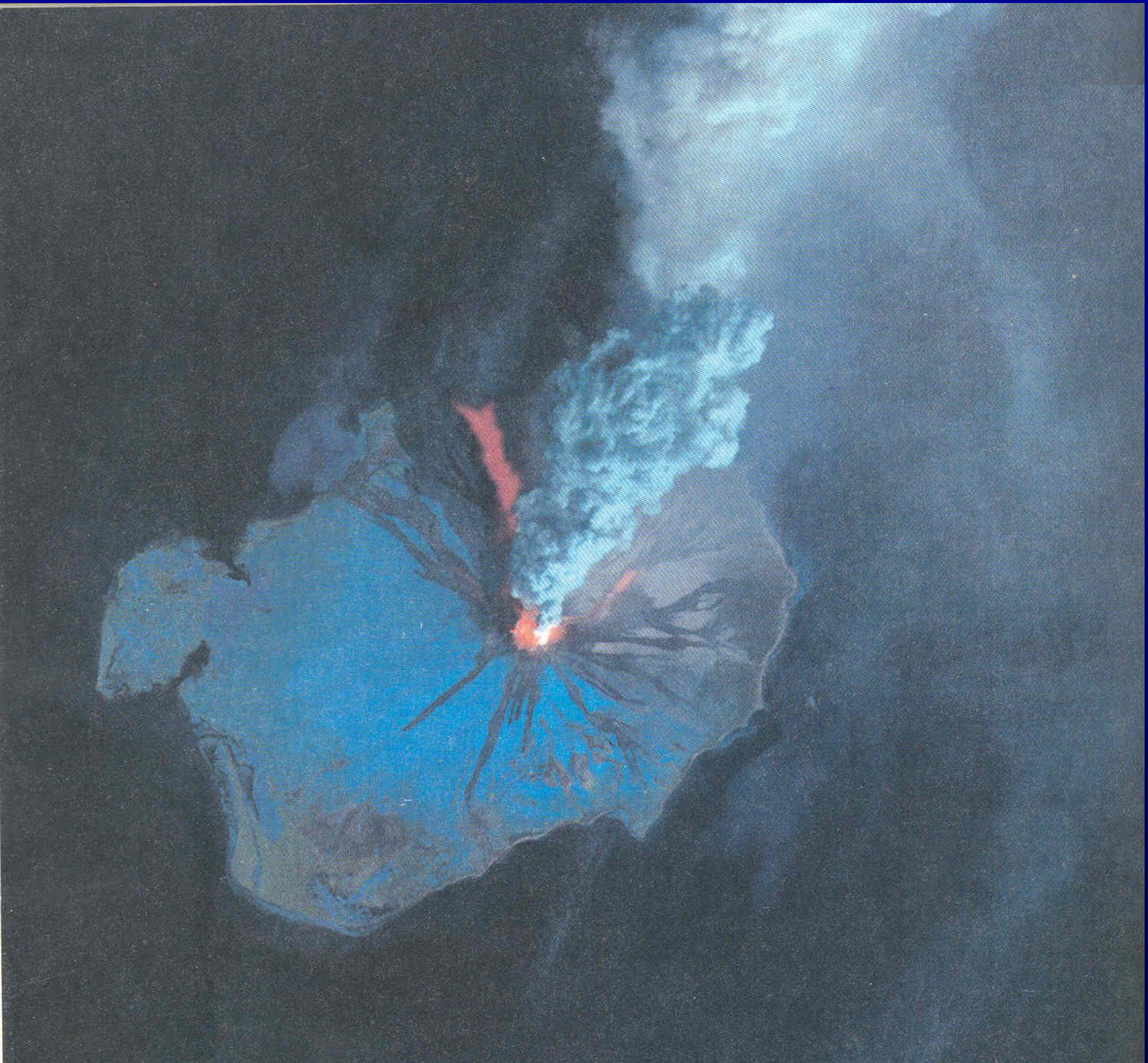
Mount St. Helens

Yellowstone caldera

Global distribution of volcanoes



VOLCANO, AUGUSTINE ISLAND, ALEUTIAN ISLAND ARC



This image was recorded by Landsat 5. Red represents flowing hot ash, blue indicates snow and gray-brown shows flows of cool ash. This type of explosive eruption represents a fundamental type of volcanism resulting from converging tectonic plates.

Eruption Types

- **Hawaiian: Volcanoes with mild eruption belong to this phase is free from explosion (e.g. Hawaiian volcanoes). Lava is ejected mildly. Such quite eruption build shield volcanoes and lava plateaus and plains. Low silica basaltic composition make the lava mobile.**

- **Strombolian: Eruption of lava punctuated by periodic, mild explosions is known as Strombolian phase. (e.g. Stromboli, Italy). In this type of eruption lava is ejected out in fountains with bombs and scoria and light-colored clouds (mostly steam) reach upward only to moderate heights.**

- **Vulcanian: More Viscous and less mobile lavas; allowing gas buildup below surface; over longer periods of quiet until lava crust is broken up, ejecting bombs, pumice, ash and thick clouds and built the Composite cone. (e.g. Vulcano, Sicily)**

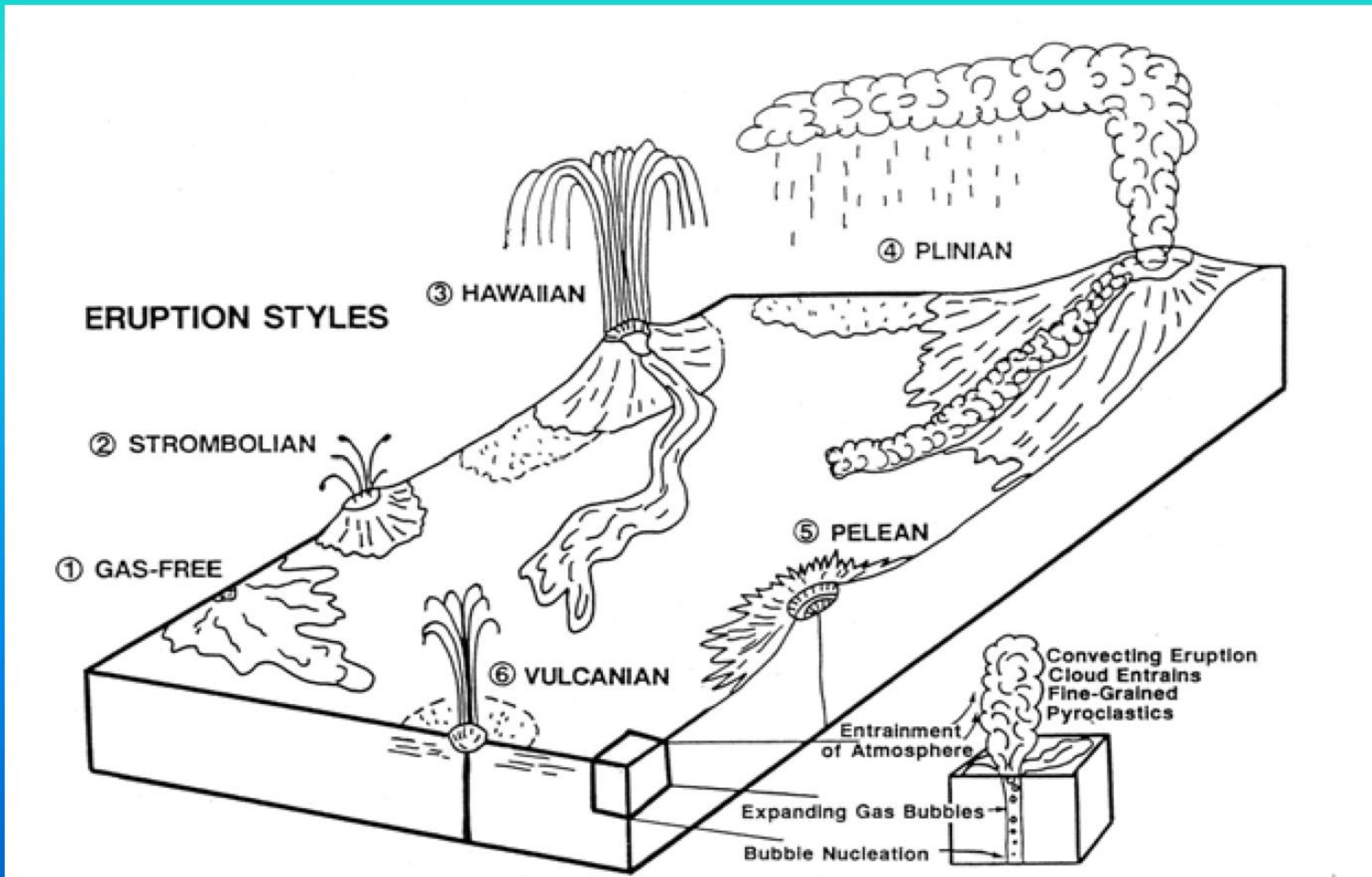
•**Vesuvian:** More stronger then Strombolian or Vulcanian types; extremely violent expulsion of gas; eruption occurs after long interval of quiescence of mild activity; vent tends to be emptied to considerable depth; lava ejects in explosive spray, repeated clouds (cauliflower) that reach great heights and deposit tephra.

•**Plinian**: More violent form of Vesuvian eruption; Calderas are formed. Volume of erupted materials is enormous. It is named after the observer Pliny who lost his life during the observations.

•**Pelean:** Results from high-viscosity lavas, erupts pyroclastics in violent explosion, forming the Volcanic domes, Glowing cloud is typical are typical feature of Pelean phase (e.g. Mount Pelee, West Indies)

No volcano erupts in the same manner through out its life. A single Volcano may erupt in different types at different times

Eruption styles
based on example volcanoes



Wilson and Head, 1994

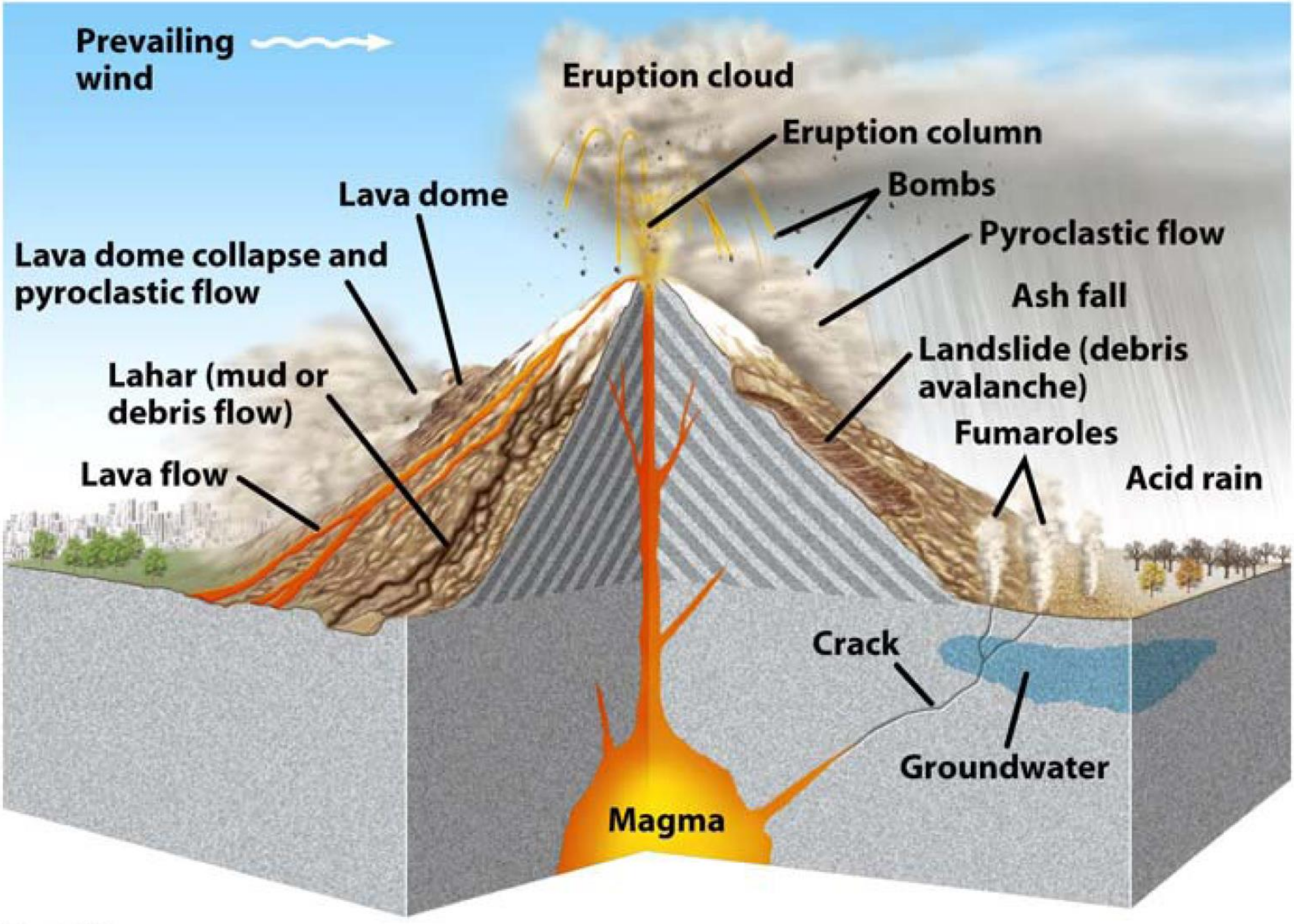
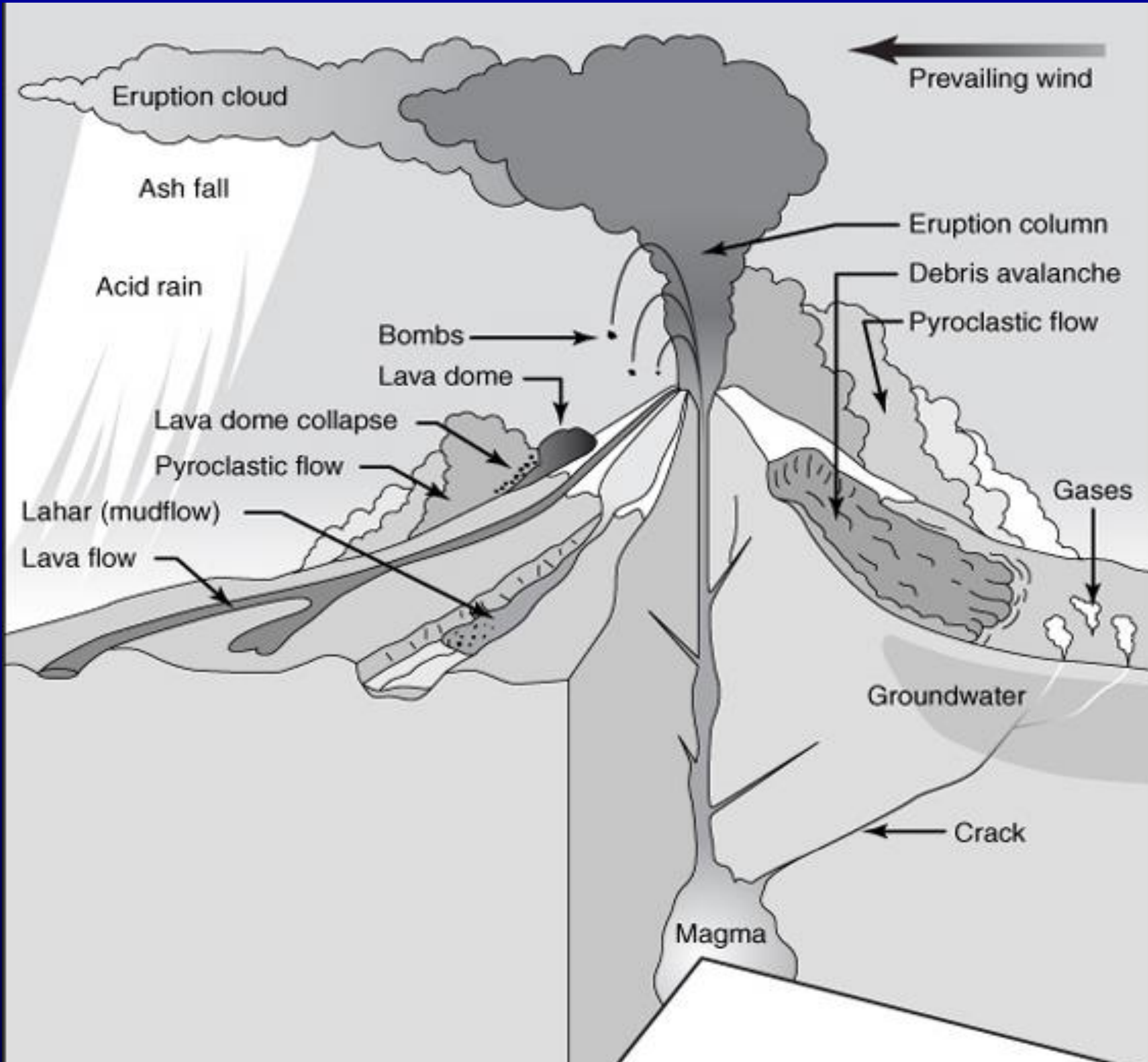


Figure 12-25
Understanding Earth, Fifth Edition


Prevailing wind
Eruption cloud
Ash fall
Acid rain
Eruption column
Debris avalanche
Pyroclastic flow
Bombs
Lava dome
Lava dome collapse
Pyroclastic flow
Lahar (mudflow)
Lava flow
Gases
Groundwater
Crack
Magma

Volcanic Hazards

- **Lava flows**
- **Pyroclastic flow and falls**
- **Ash flows**
- **Lahars and Debris Avalanches**
- **Volcanic gases**
- **Volcanic dome collapse**
- **Caldera collapse**
- **Eruption clouds**
- **Landslides**
- **Seismicities**
- **Tsunami**

LAVA FLOWS

- This is a basalt lava flow in a channel
- Due to its low silica content and high temperature, it is quite fluid
- Yet lava usually flows fairly slowly and cause damages

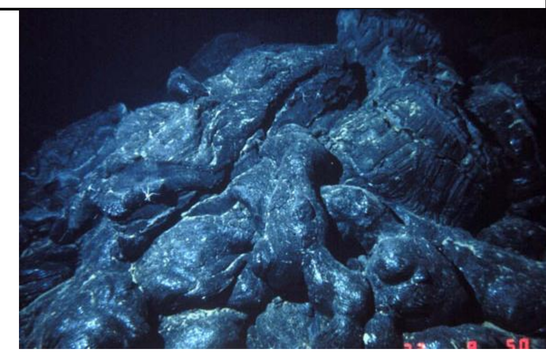
Lava Flows

- **lava**: magma that reaches Earth's surface
- temp. & speed affect appearance of hardened surface

- **ON LAND**
  - Hotter basaltic lava
    - Flows quickly out of vents
      - Forms pahoehoe
        - » Smooth, ropelike surfaces

  - Cooler basaltic lava
    - Moves slowly, cools quickly
      - Forms aa
        - » Rough, jagged surfaces

- **UNDERWATER**
  - Distinctive shape
    - Rounded, pillow-like, hard crust
      - Forms pillow lava



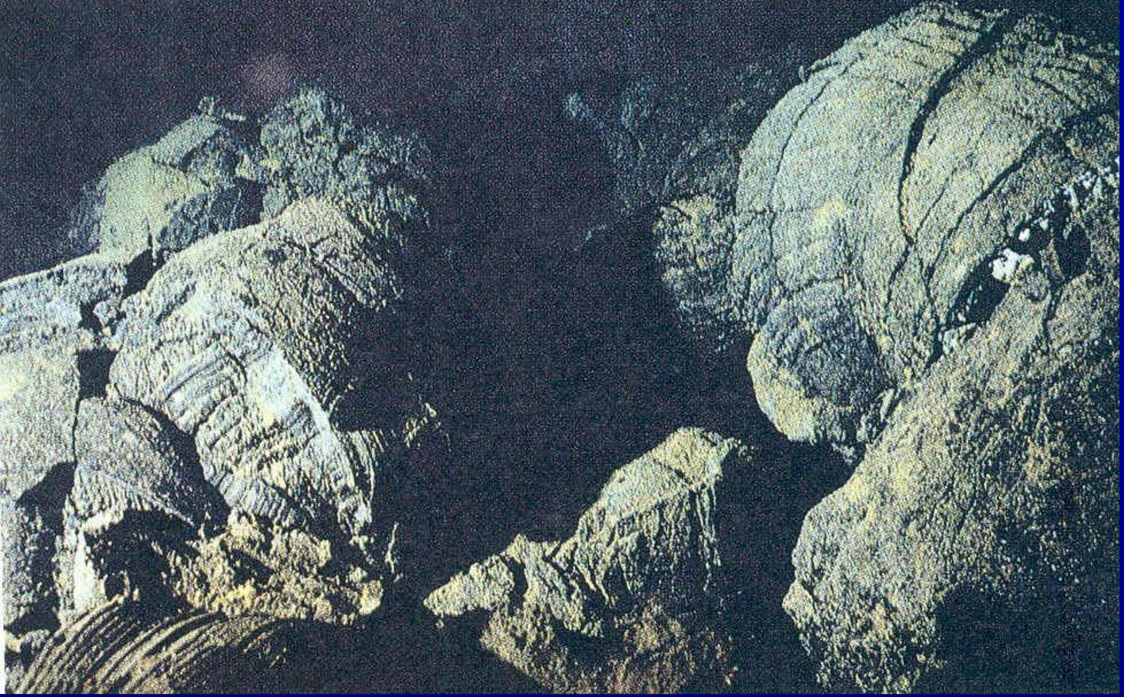
Pahoehoe lava

This is a Hawaiian term for smooth, ropy lava

It generally exhibits fluid-like textures

Aa lava

- This type of lava is quite blocky on the surface, and comparatively cool
- Yet below the surface, the lava is fairly massive and much hotter
- Also called Blocky Lava



It was photographed at close range by scientists in the deep-diving submersible *Alvin*. Little or no sediment covers the basalt because this part of the sea floor is very young. The large elliptical structure is approximately 1 m long.

PILLOW BASALT, MID ATLANTIC RIDGE

Tubular-shaped pillows of basalt photographed in the central rift of the East Pacific Rise, at a water depth of about 500 m.

Flood basalts

- The previous examples represent small-scale activity
- But basaltic eruptions can be huge, forming lava plateaus
- These huge outpourings may occur quickly (1-3 Ma) and may contribute to mass extinctions

- (e.g. Deccan Plateau, Columbia Plateau)

Volcanic activity: Pyroclastic flows

- **“A *Pyroclastic flow* is a fluidized mixture of solid fragments and hot, expanding gases that flows down the volcano vent.**
- **Pyroclastic flows are suspensions of hot pyroclastic material, air, and gas which descend under the influence of gravity**
- **Their velocity is generally very high (50-500 km/hr)**
- **This example is a flow from Mt. St. Helens**

Pyroclastic falls

- During explosive volcanic eruptions, ash falls downwind of the volcano

- In the case of very large eruptions, the ash may be deposited over a vast area

Pyroclastic flows

- **This is another example, descending the slopes of Unzen volcano after part of the dome has collapsed**
- **The flow has a dense core which is hidden by the billows of ash which are rising**

Unzen, 24 June 1993

Pyroclastic flows - note big rounded pumices

Ash & Rock Fragments

- Explosive eruptions usually involve magmas which contain trapped gasses
  - When gasses are released, solid pyroclastic material may be ejected
    - Classified by size
      - Smallest → ash
      - Intermediate → lapilli
      - Largest → blocks & bombs

- If pyroclastic materials combine with hot gasses → pyroclastic flow (dense, superheated cloud that travels downhill with amazing speed)

Volcanic dust and ash:

➔ **Volcanic dust consisting of particles having less than 2.5 mm diameter**

➔ **Volcanic dust comprising particles less than 4mm in diameter**

➔ **They are fine particles traveling through upper atmosphere and take several years settle. Hardened ash is called Tuff**

Lapilli: **Lapilli are larger particle than ash and dust, 4mm to 32 mm in diameter**

Bombs: **Bombs are elliptical or oval shaped pieces with twisted ends called volcanic bombs**

Pumice: **A lava foam is formed when there is sudden release of gas pressure**

Scoria: **When lava flows are extremely vesicular giving a spongy look they are described as scoriaceous**

If a volcano's lava is thick and stiff, the lava may explode into the air and harden into ash, cinders, and bombs.

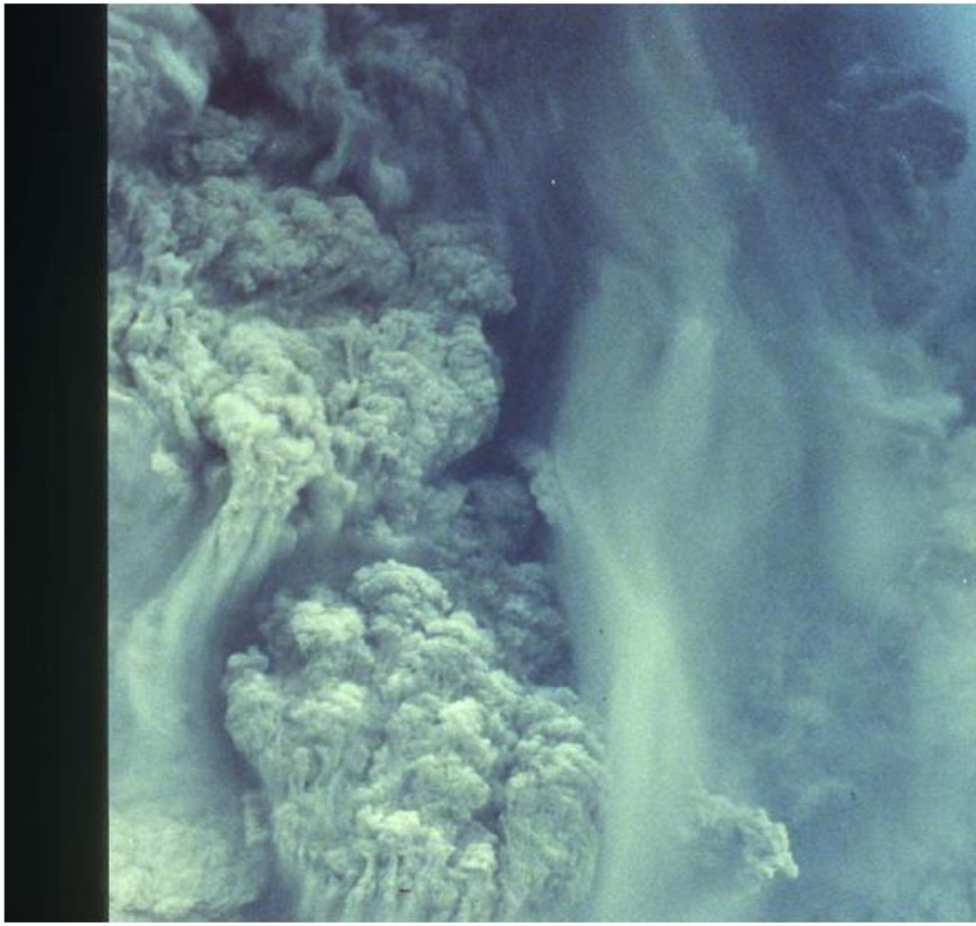
VOLCANIC BOMBS

Volcanic blocks

Lapilli

Volcanic bombs

Volcanic ash



Ashfall is an extensive hazard from volcanoes, Ste Helens ash was widely distributed

Volcanic activity: lahars

- **Lahar is an Indonesian word for volcanic debris flow**
- **Lahars are flows of water and loose volcanic debris**
- **They are especially prevalent at snow-clad and ice-clad volcanoes**

Lahars on snow/glacier clad volcanoes

Major changes in valley floor elevation after single lahar has formed after typhoon.

The impact on villages within the path of a lahar can be extreme

While old houses are buried, new homes are built on stilts to try to avoid the next lahar

An old church has been partially-buried so that you now enter on the 2nd floor. Ronnie Torres shows the church prior to the lahars.

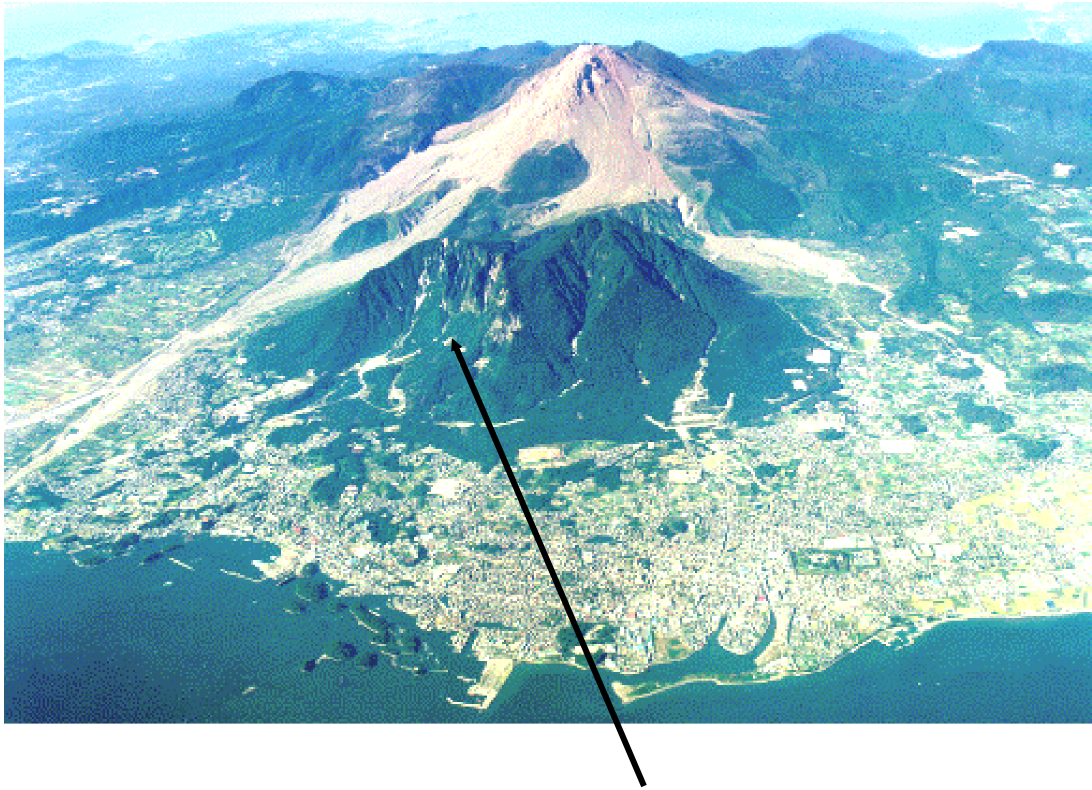
Some homes, once buried by lahar, and now being exposed by recent erosion

The human cost at Armero

- A victim just after rescue from the lahar
- She is completely coated in the mud of the lahar
- In general, survivors had great difficulty extricating themselves

Volcanic activity: debris avalanches

- **Sometimes a volcanic structure is <u>weakened</u>**
- **Wholesale <u>collapse</u> of part of the volcano may result**
- **During collapse, a debris avalanche occurs, and a scar remains**



Unzen volcano, with the 1792 scar in the foreground

Volcanic activity: gases

- Volcanic gases are typically <u>highly acid</u>

- Major constituents include H_2O, CO_2, HCl, SO_2, and HF

- This photo shows gas emission from Masaya volcano in Nicaragua

Volcanic activity: gases

- This is also Masaya volcano…
- but this photo was taken from the space shuttle
- it shows the gas plume being blown out over the Pacific Ocean

Masaya, Nicaragua Space Shuttle Image (61C-36-10)

Volcanic activity: gases

- **About 15 km downwind from Masaya, the coffee crop is adversely affected by the acid gases**

Fire Fountaining

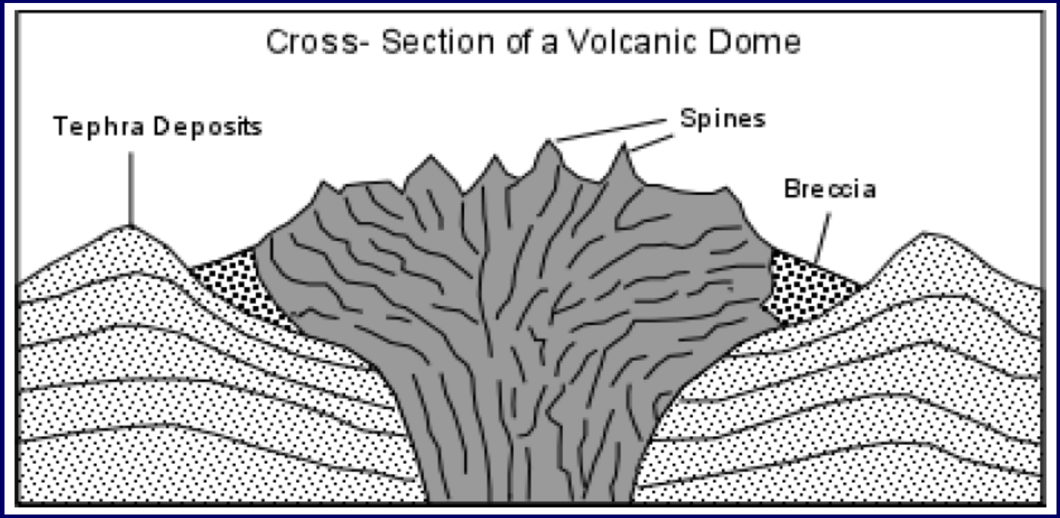
- **Sometimes, basaltic lava <u>can</u> contain lots of gas**
- **Then, small explosive eruptions form fire fountains**
- **As partially liquid drops fall back to the ground, they may coalesce to form a lava flow**

Lava Domes (also called **Volcanic Domes**)

Volcanic Domes result from the extrusion of highly viscous, gas poor andesitic and rhyolitic lava. Since the viscosity is so high, the lava does not flow away from the vent, but instead piles up over the vent.

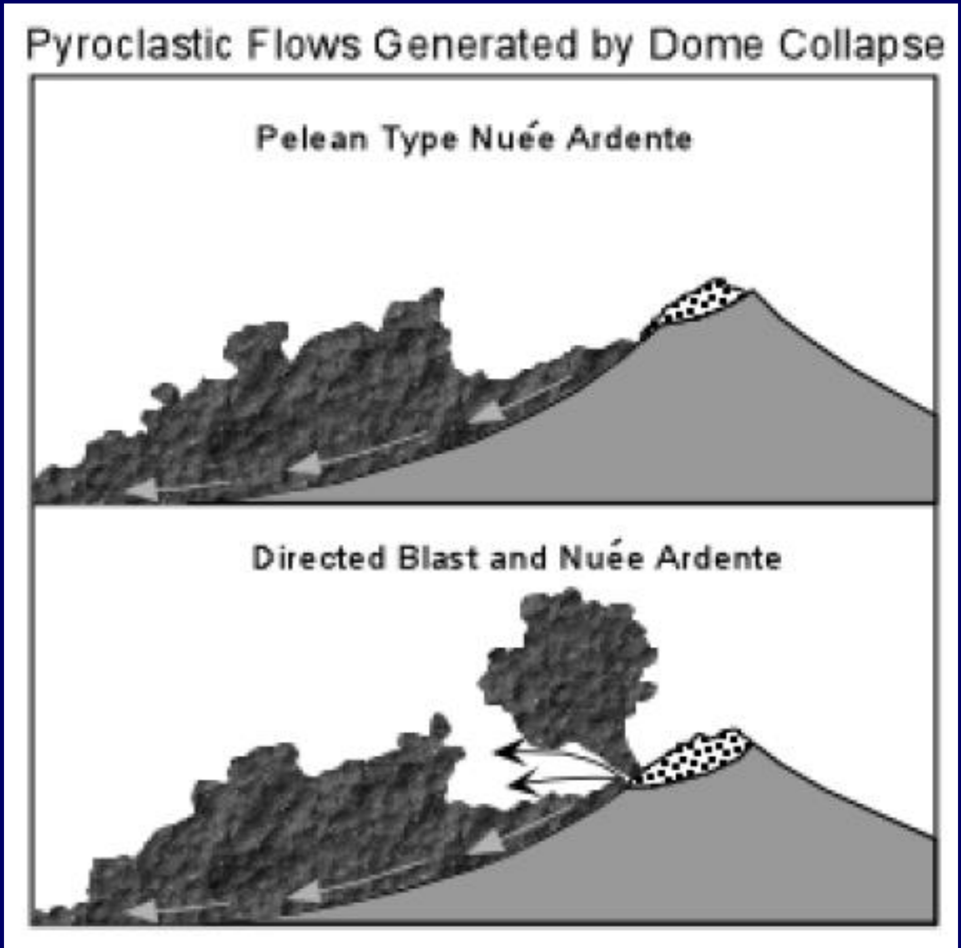
Blocks of nearly solid lava break off the outer surface of the dome and roll down its flanks to form a breccia around the margins of domes.

The surface of volcanic domes are generally very rough, with numerous spines that have been pushed up by the magma from below.



Most dome eruptions are preceded by explosive eruptions of more gas rich magma, producing a tephra cone into which the dome is extruded.

Volcanic domes can be extremely dangerous. because they form unstable slopes that may collapse to expose gas-rich viscous magma to atmospheric pressure. This can result in lateral blasts or Pelean type pyroclastic flow (nuéeardentes) eruptions.



Volcanic activity: lava domes

- By early 1995, the dome complex had grown substantially and was highly oversteepened

- As pieces of the dome broke off, they would fragment, creating <u>pyroclastic flows</u>

Dome growth-destruction cycles

Sizes of volcanic eruptions

- The Volcano Explosivity Index (VEI) is similar to the Richter scale for quakes
- It is logarithmic
- It emphasizes the degree of explosivity of eruptions

Volcano Explosivity Index (VEI)

VOLCANIC EXPLOSIVITY INDEX (VEI) (p. 23-25)

	0	1	2	3	4	5	6	7	8
General Description	Non-Explosive	Small	Moderate	Moderate-Large	Large	Very Large			
Volume of Tephra (m^3)	1×10^4	1×10^6	1×10^7	1×10^8	1×10^9	1×10^{10}	1×10^{11}	1×10^{12}	
Cloud Column Height (km)									
Above crater	<0.1	0.1-1	1-5						
Above sea level				3-15	10-25	>25 ⟶			
Qualitative Description	"Gentle,"	"Effusive"	⟵ "Explosive" ⟶		⟵ "Cataclysmic,"		"paroxysmal,"	"colossal" ⟶	
				⟵ "Severe,"		"violent,"	"terrific" ⟶		
Eruption Type		⟵ Strombolian ⟶		⟵ Plinian ⟶					
	⟵ Hawaiian ⟶		⟵ Vulcanian ⟶			⟵ Ultra-Plinian ⟶			
Eruptions (total in file)	699	845	3477	869	278	84	39	4	0

Predict eruptions

Measuring Small Quakes

– **Before eruption, increase in number & intensity**

Measuring Slope

– **Bulges may form with magma (tiltmeter, GPS, SAR interferrometry)**

Measuring Volcanic Gases

– **Outflow of volcanic gases**

  - **Sulfur dioxide, carbon dioxide**

Measuring Temperature from Orbit

– **Measure changes in temperature over time**

Stages at Mt. St. Helens Washington state, USA

- **Stage 1:** precursory activity, 20 March - 18 May 1980
- **Stage 2:** the climactic eruption of 18 May 1980
- **Stage 3:** post-climactic activity, 1980-present

<u>Stage 1:</u> Precursory activity; eruptions

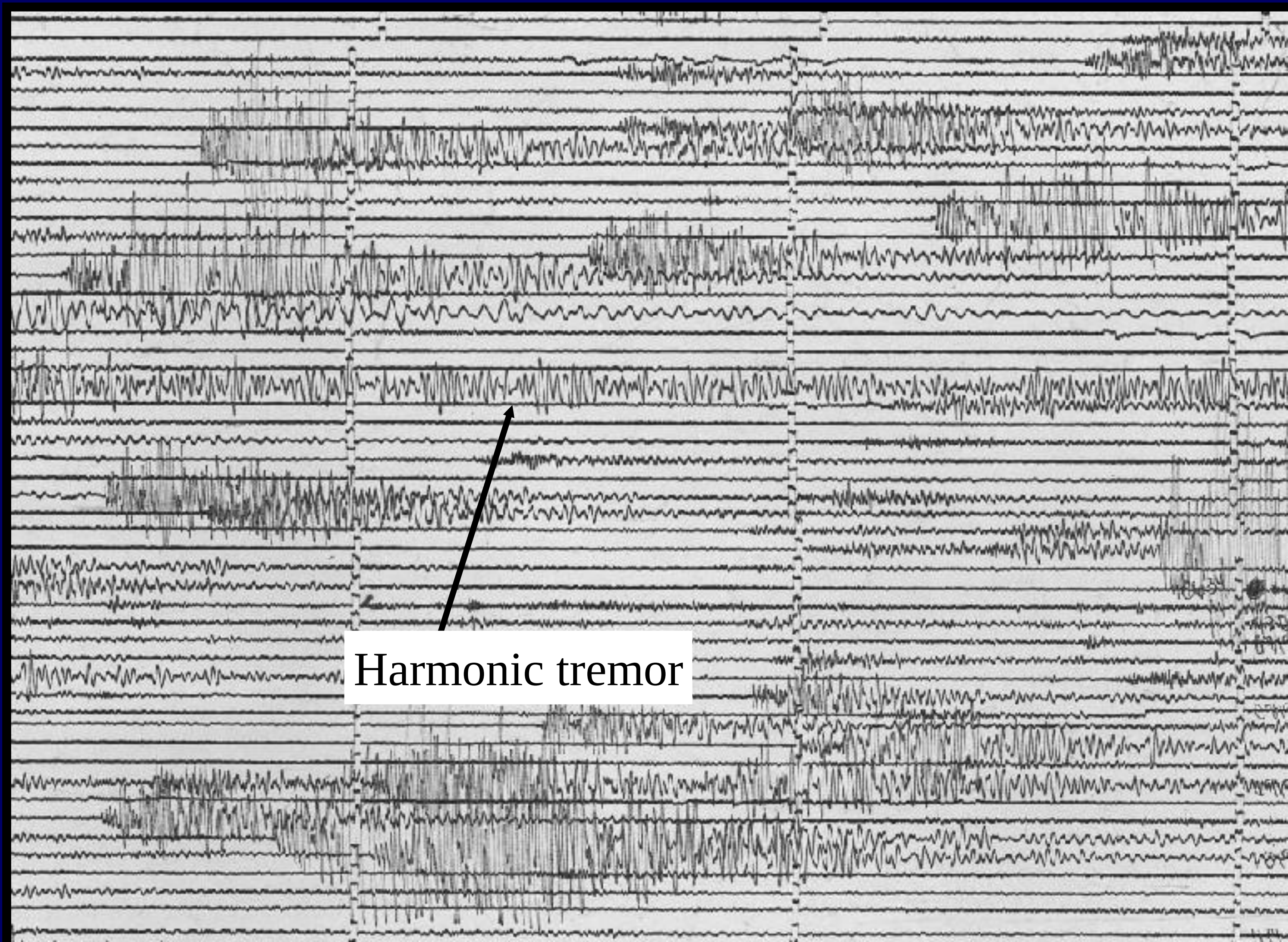
- The first phreatic eruption occurred on 27 March 1980
- then explosions continued…the volcano was preparing itself
- The eruptions of 13, 18 April consisted of steam and ash

27 March 1980 eruption

Precursory activity: seismicity

- A magnitude 4.1 earthquake was recorded on 20 March 1980 under the volcano
- By 1 April, harmonic tremor was observed (continuous seismic signal of similar wavelength)
- this is a pretty good indication that magma is involved

A seismogram from seismic station RAN on 2 April showing the occurrence of harmonic tremor



Precursory activity: deformation

- A bulge was first detected on the NNE flank of the volcano on 19 April 1980
- Deformation was as high as 5 feet/day !
- This was an indication that magma had moved into the volcano itself
- At the same time, eruptive activity decreased during 14-23 April

Development of the bulge

28 September 1979

bulge

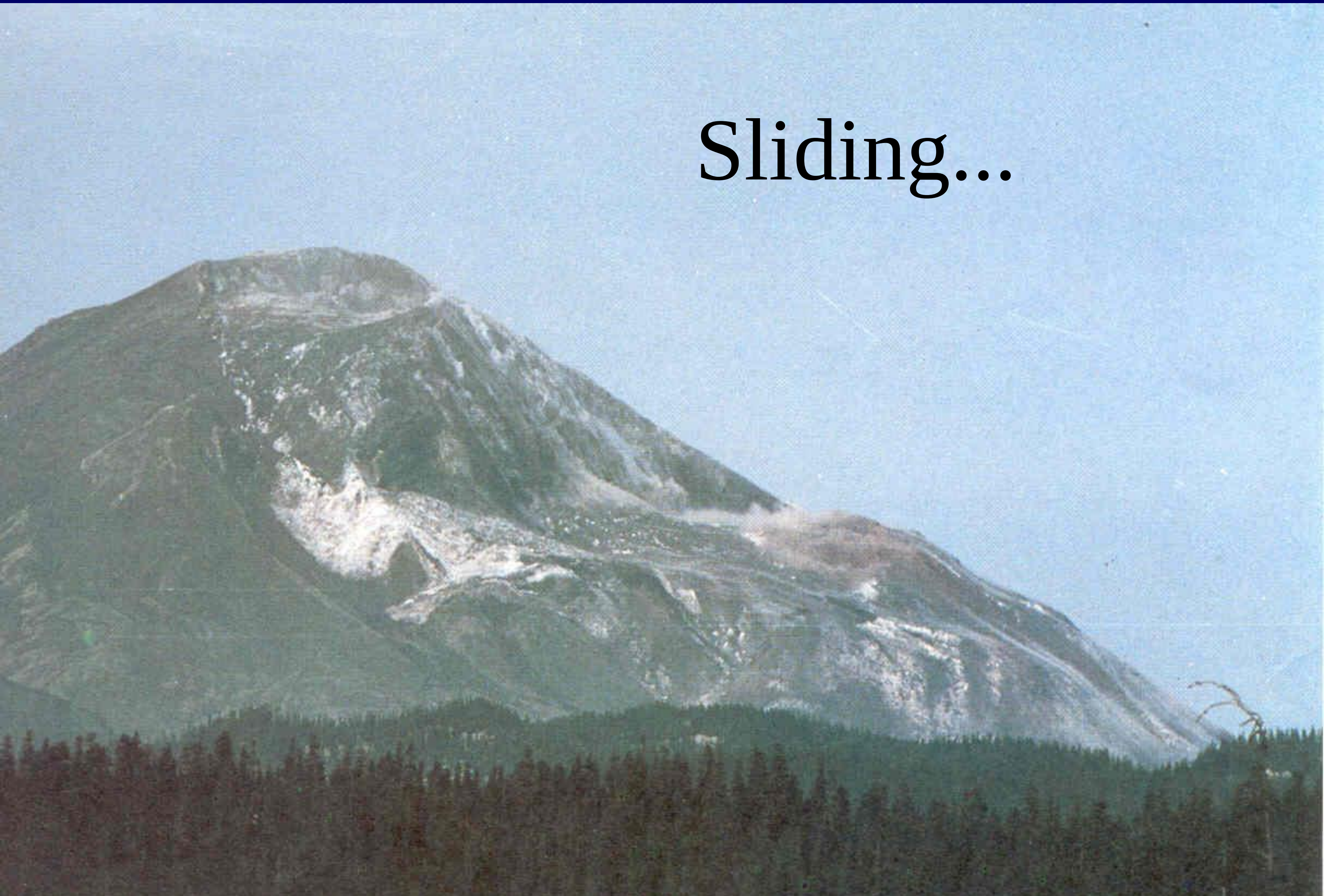
17 May 1980

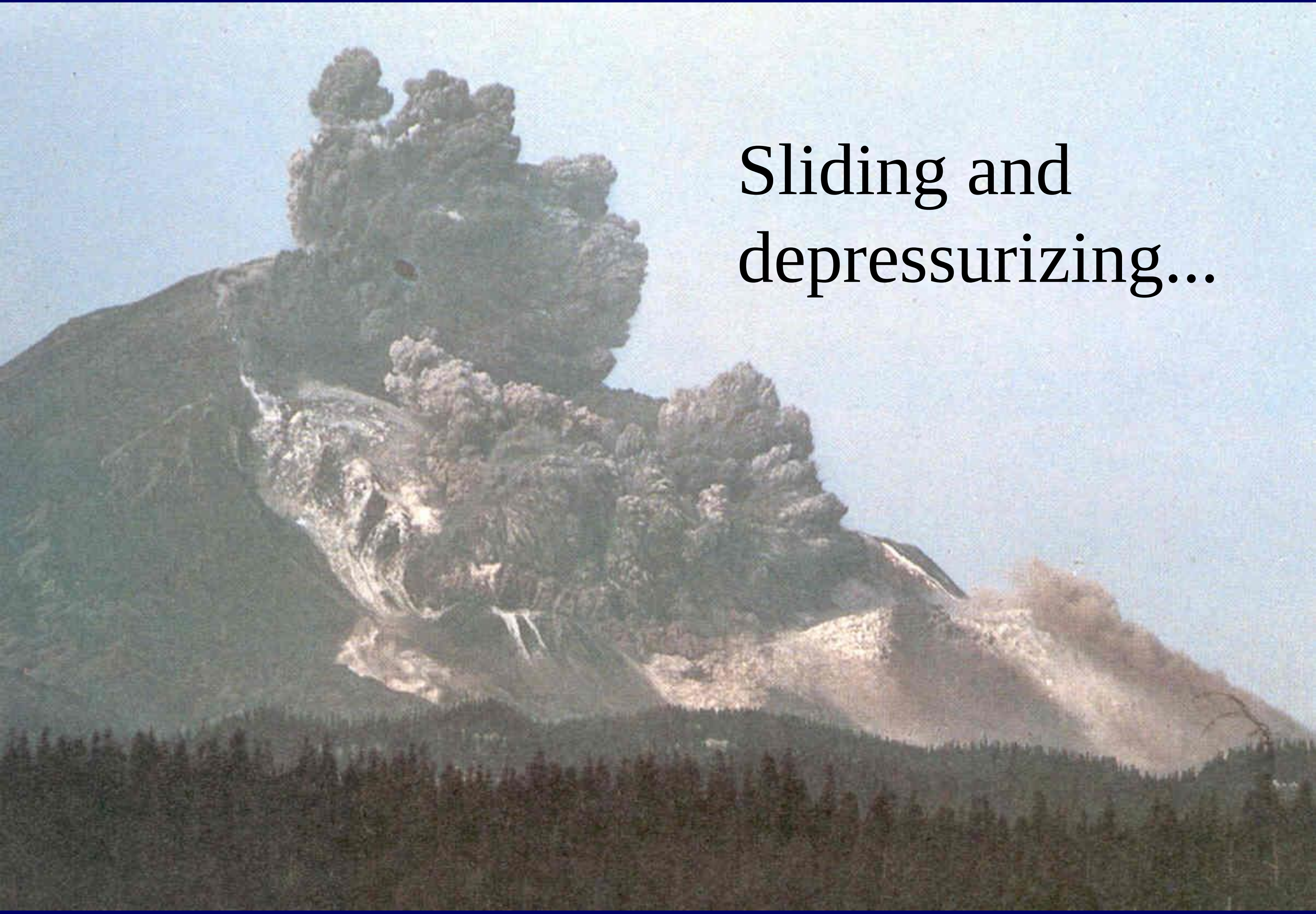
Precursory activity: gas emissions

- Although some sulfur dioxide was detected, not very much was actually being emitted
- This suggests that the volcano had somehow sealed itself, and that pressure was building
- This interpretation is consistent with (a) the bulge and (b) decreased eruptive activity

<u>Stage 2:</u> The climactic eruption, 18 May 1980

- At 0832 local time, a M 5.1 earthquake struck the volcano
- A large portion of the volcano slid away
- This simultaneously developed a debris avalanche and a lateral blast


Sliding...


Sliding and
depressurizing...


And
blasting

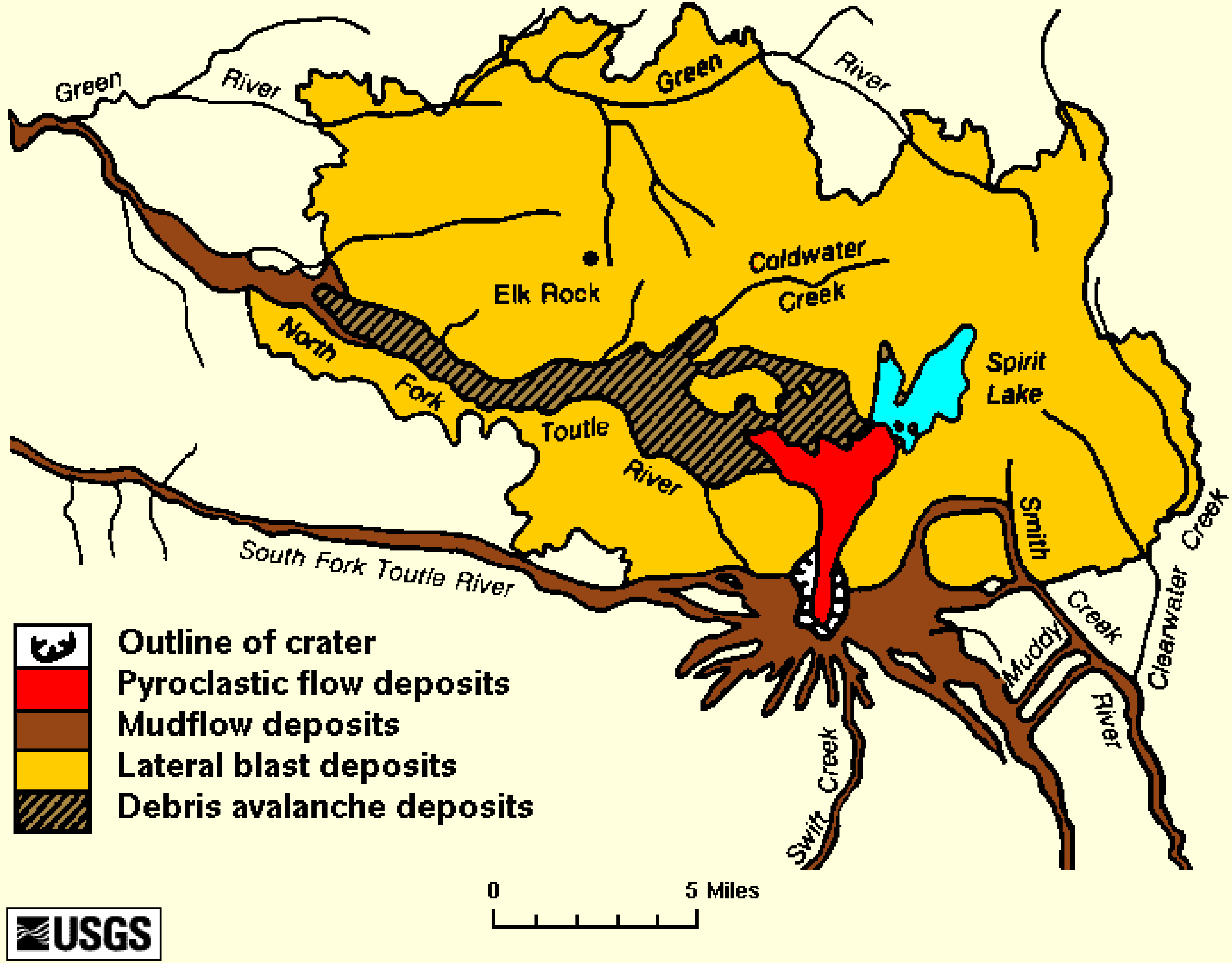
The blast

- The lateral blast was comparatively cool at 100-300° C
- But its speed approached 500 km/hr
- It was therefore devastating to a very large area (180°, up to 20 km distance)

Note trees still standing

Tree blowdown by the blast

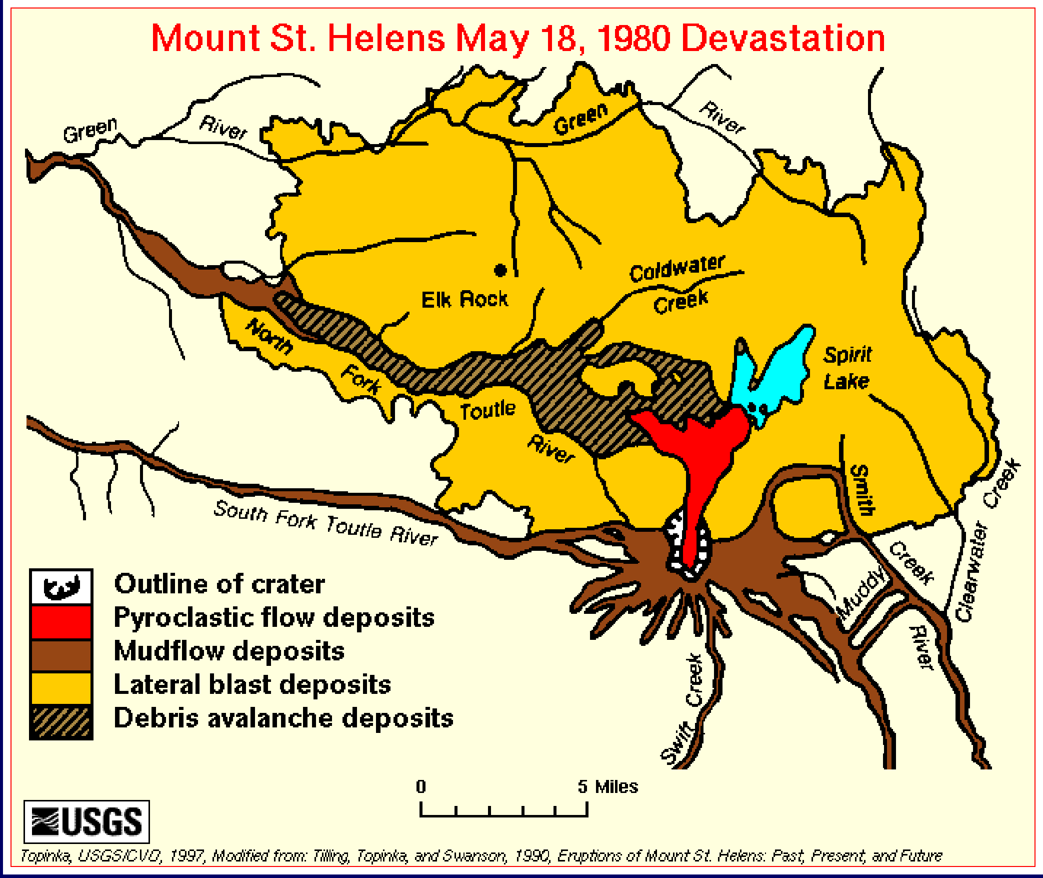
Mount St. Helens May 18, 1980 Devastation



Topinka, USGS/CVO, 1997, Modified from: Tilling, Topinka, and Swanson, 1990, Eruptions of Mount St. Helens: Past, Present, and Future

Sector collapse and the debris avalanche

- The sector collapse reduced the height of the volcano substantially
- A horseshoe-shaped amphitheatre was formed
- The avalanche deposit was emplaced in the Toutle River valley



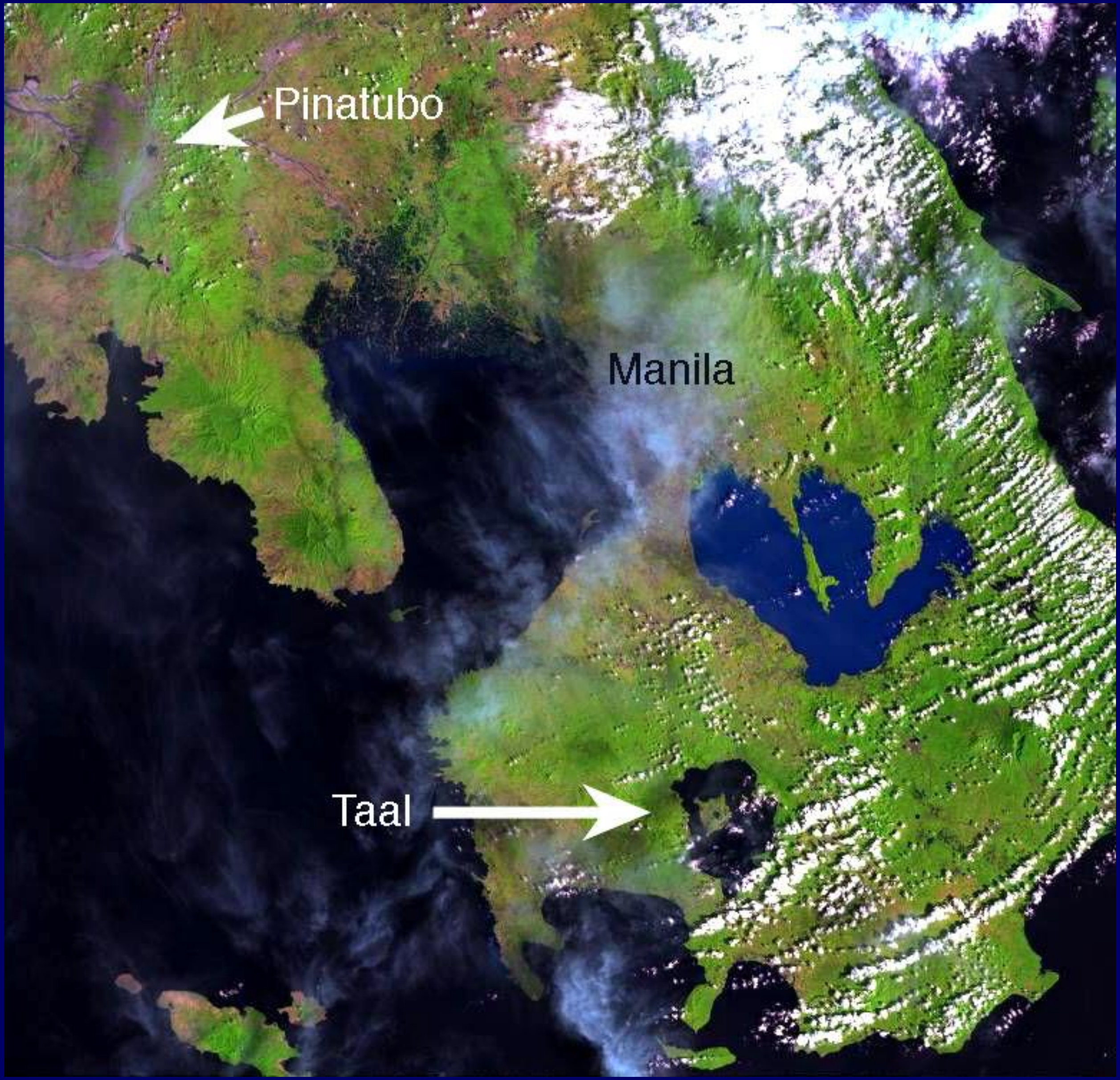
Debris carried by lahars

Note the "high-water" mud marks on the trees

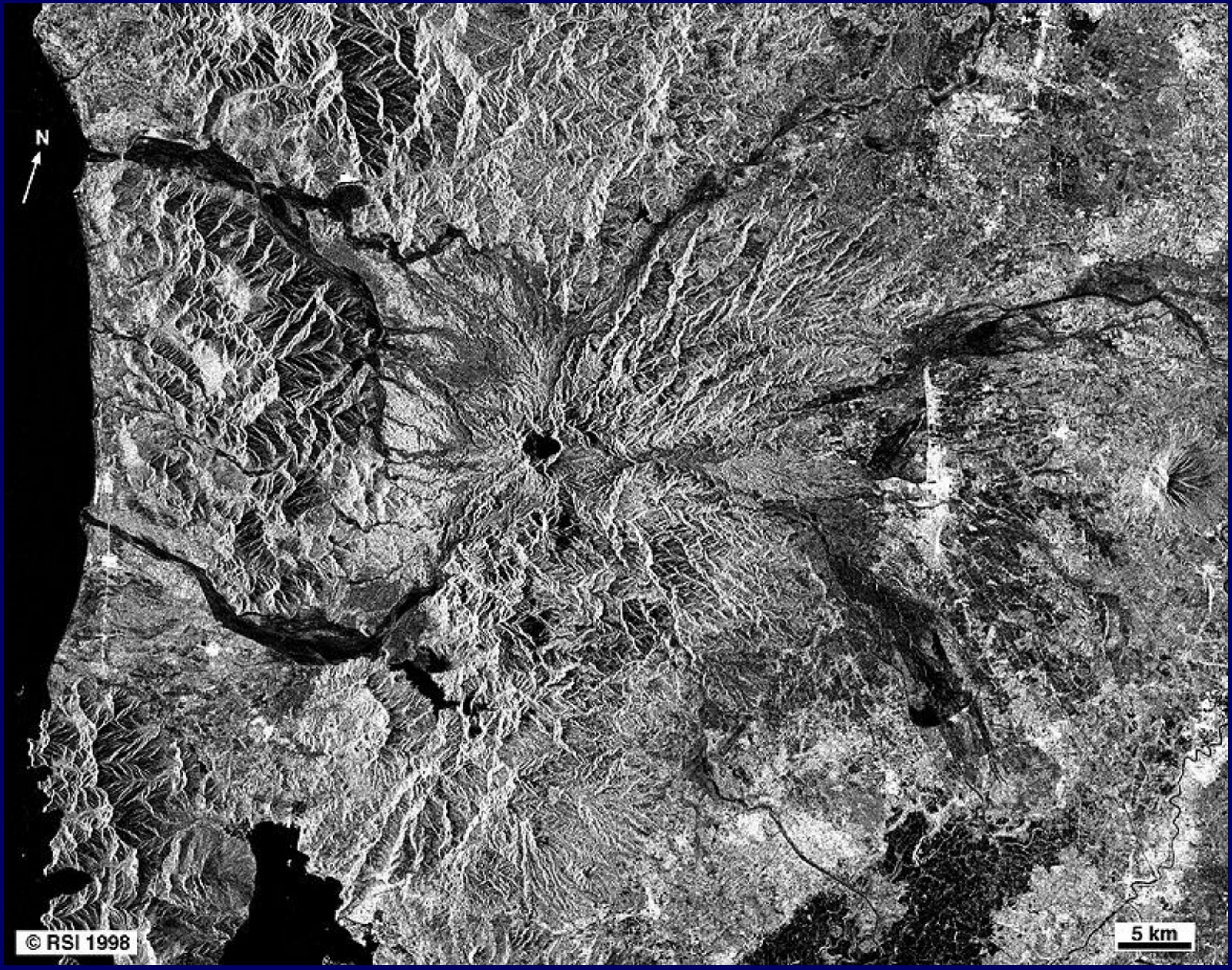
Final costs from the 18 May devastation

- 35 people dead (it was a Sunday)
- 22 people never found
- $ 2.7 billion US in damage
- contrast this with the $ 10-20 billion in losses from the 1989 Loma Prieta and 1994 Northridge earthquakes

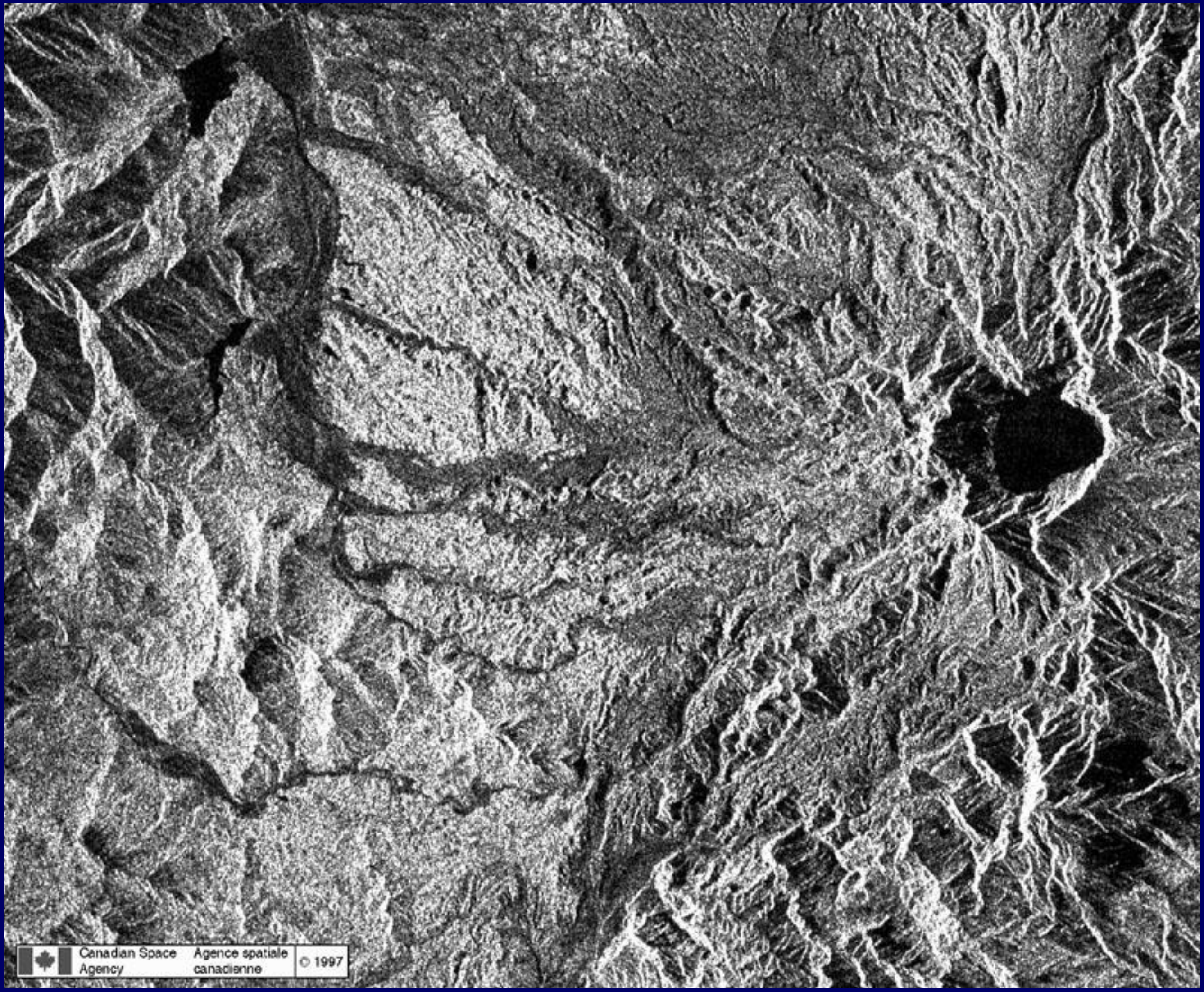
Landsat 7
Path 116
Row 50



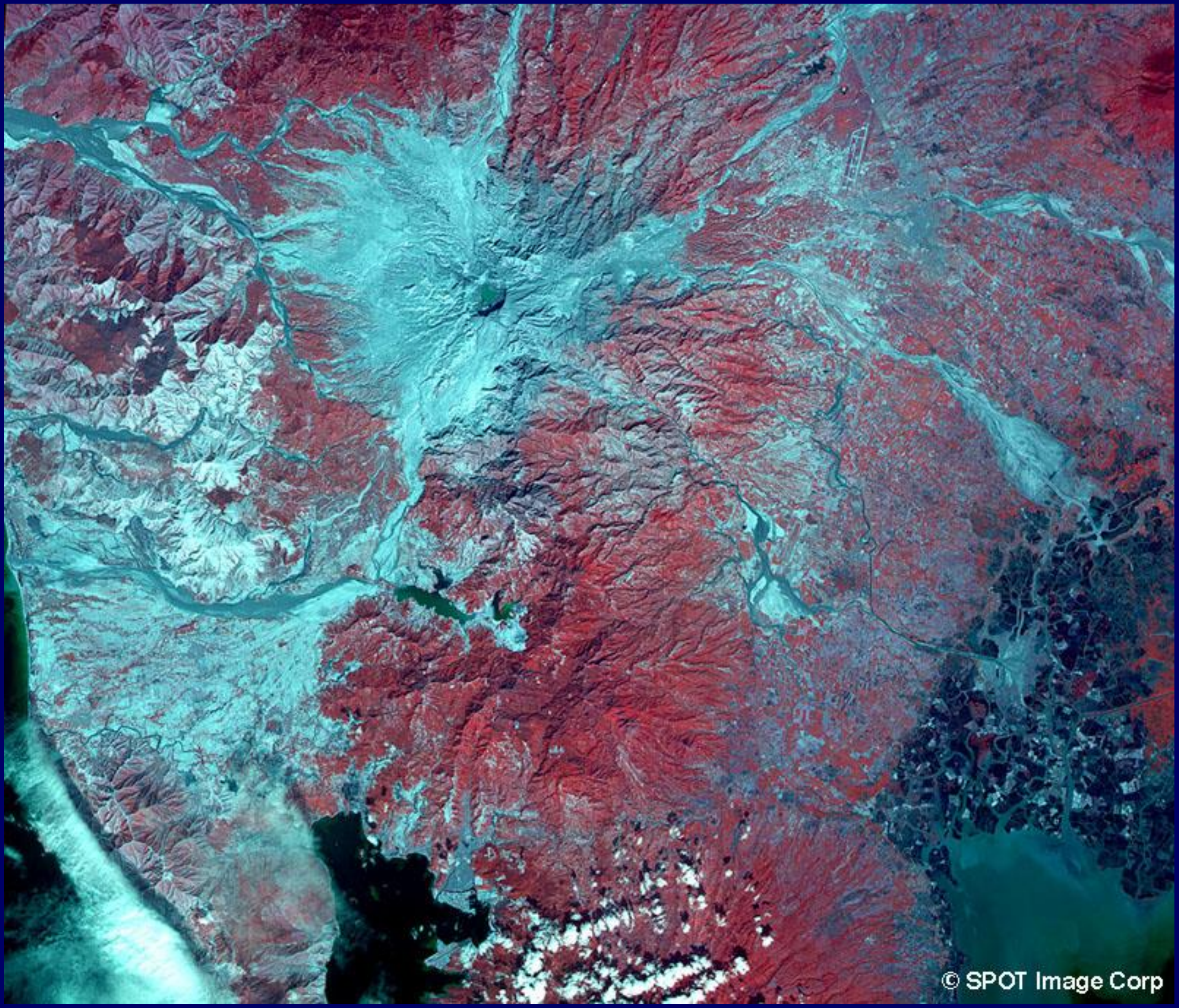
RADARSAT radar backscatter image of Mt. Pinatubo, February 1998



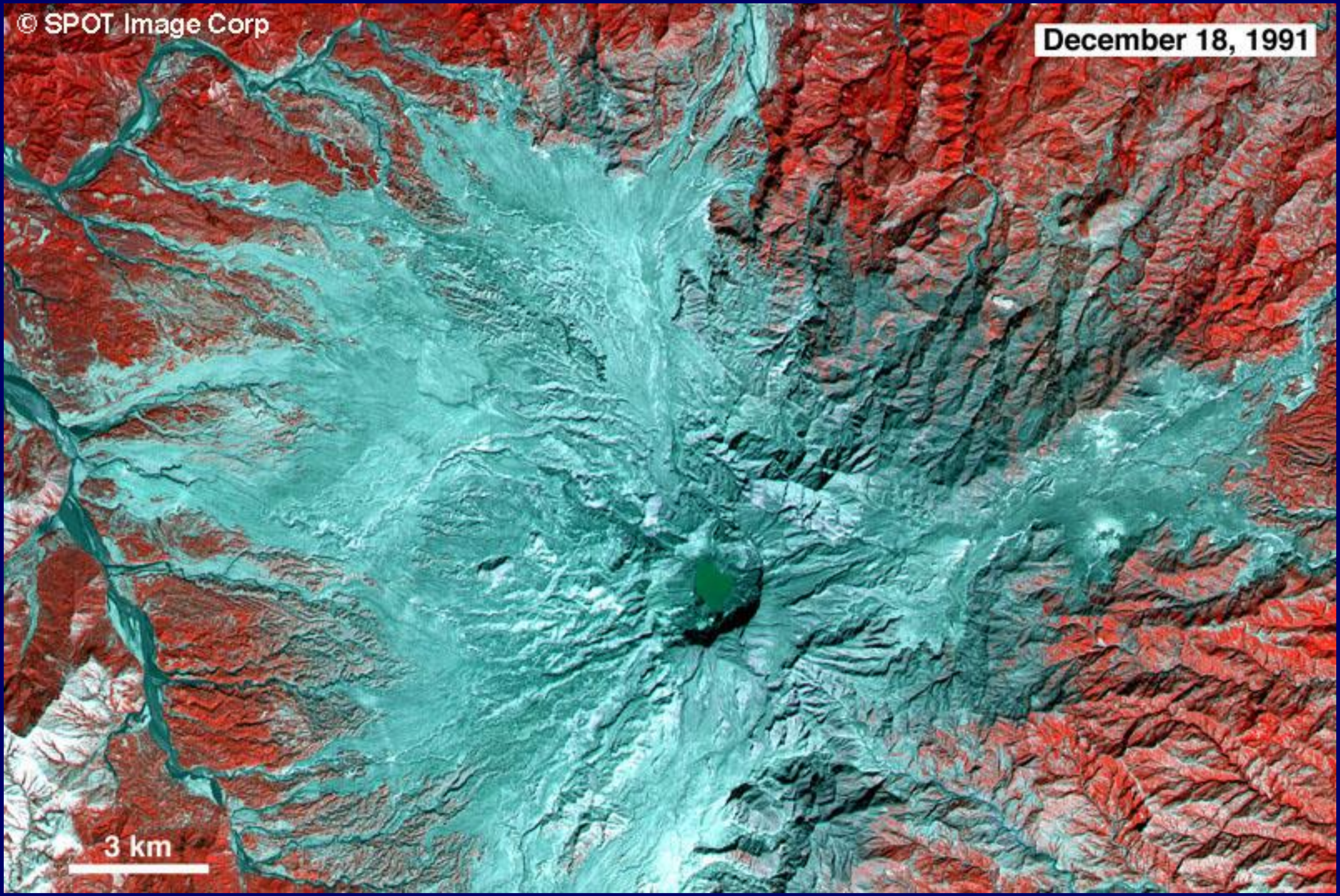
RADARSAT radar backscatter image of western fan of Mt. Pinatubo



SPOT image of Mt. Pinatubo December 1991



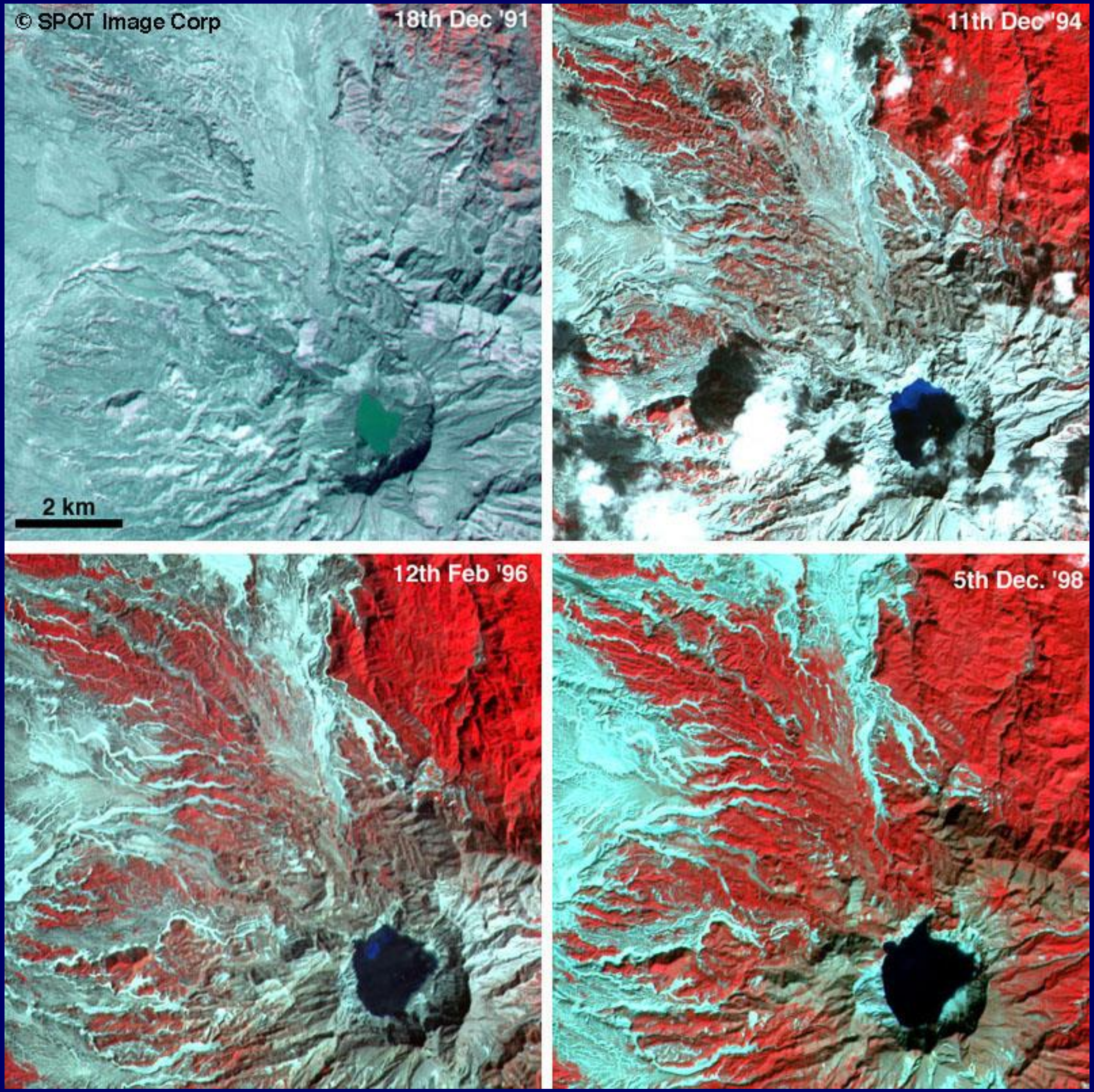
SPOT data of Mt. Pinatubo summit area soon after the eruption



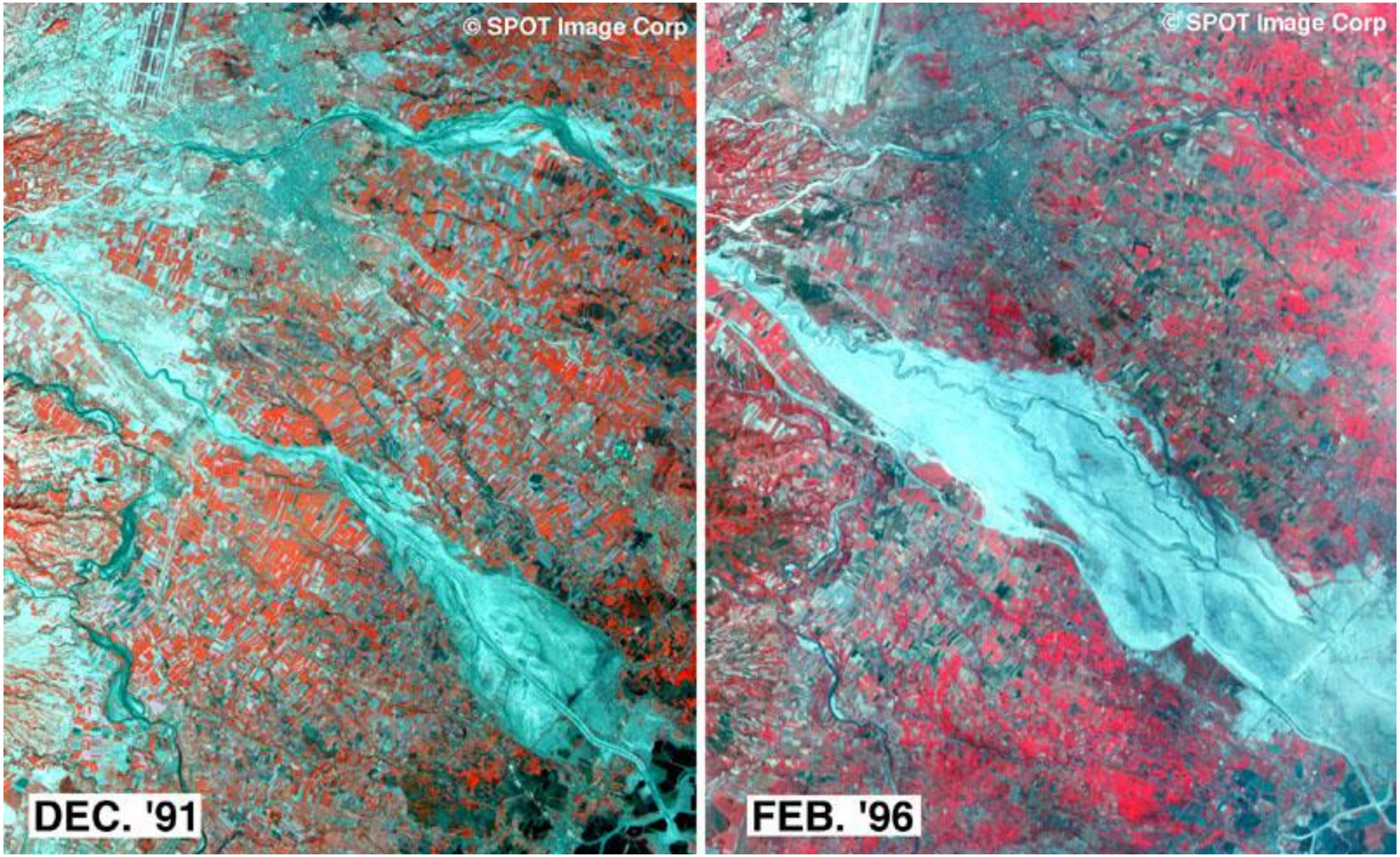
Comparison of NW Summit from SPOT data obtained between 1991 and 1998

Red shows vegetation, the ash deposits are light blue

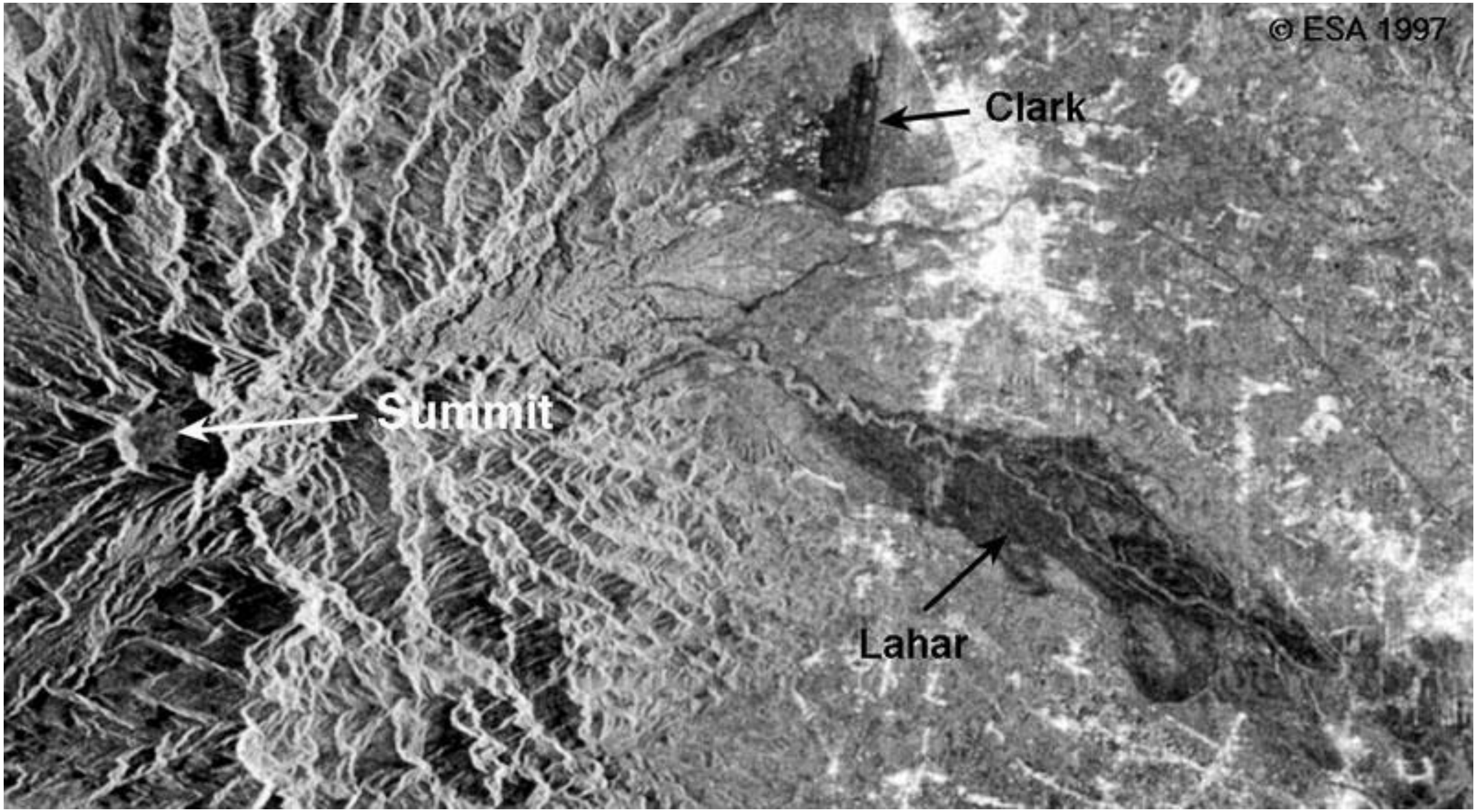
Summit is at lower right



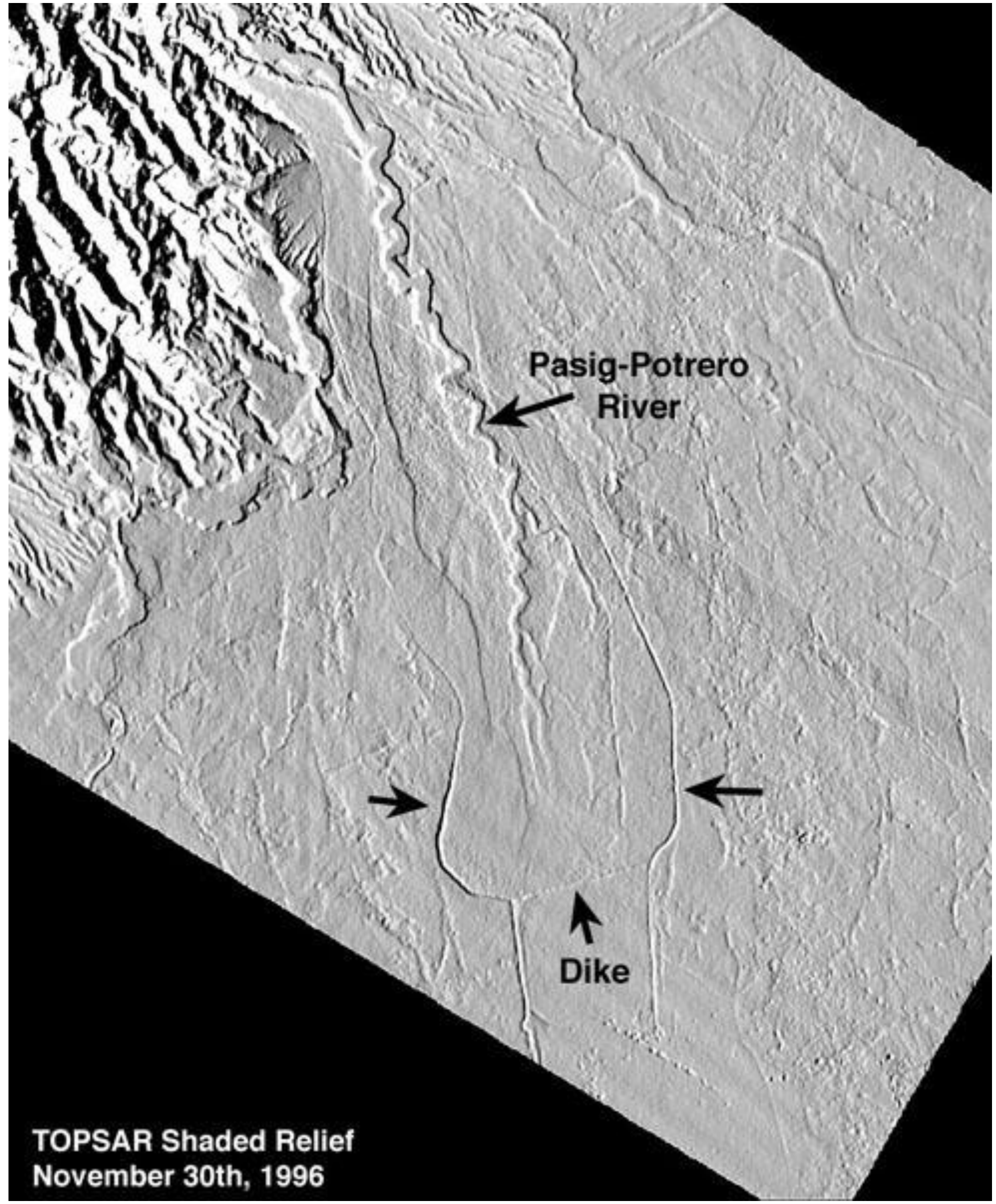
Changes in Mt. Pinatubo lahar deposits.
Lower Pasig-Potrero River 1991 - 1996



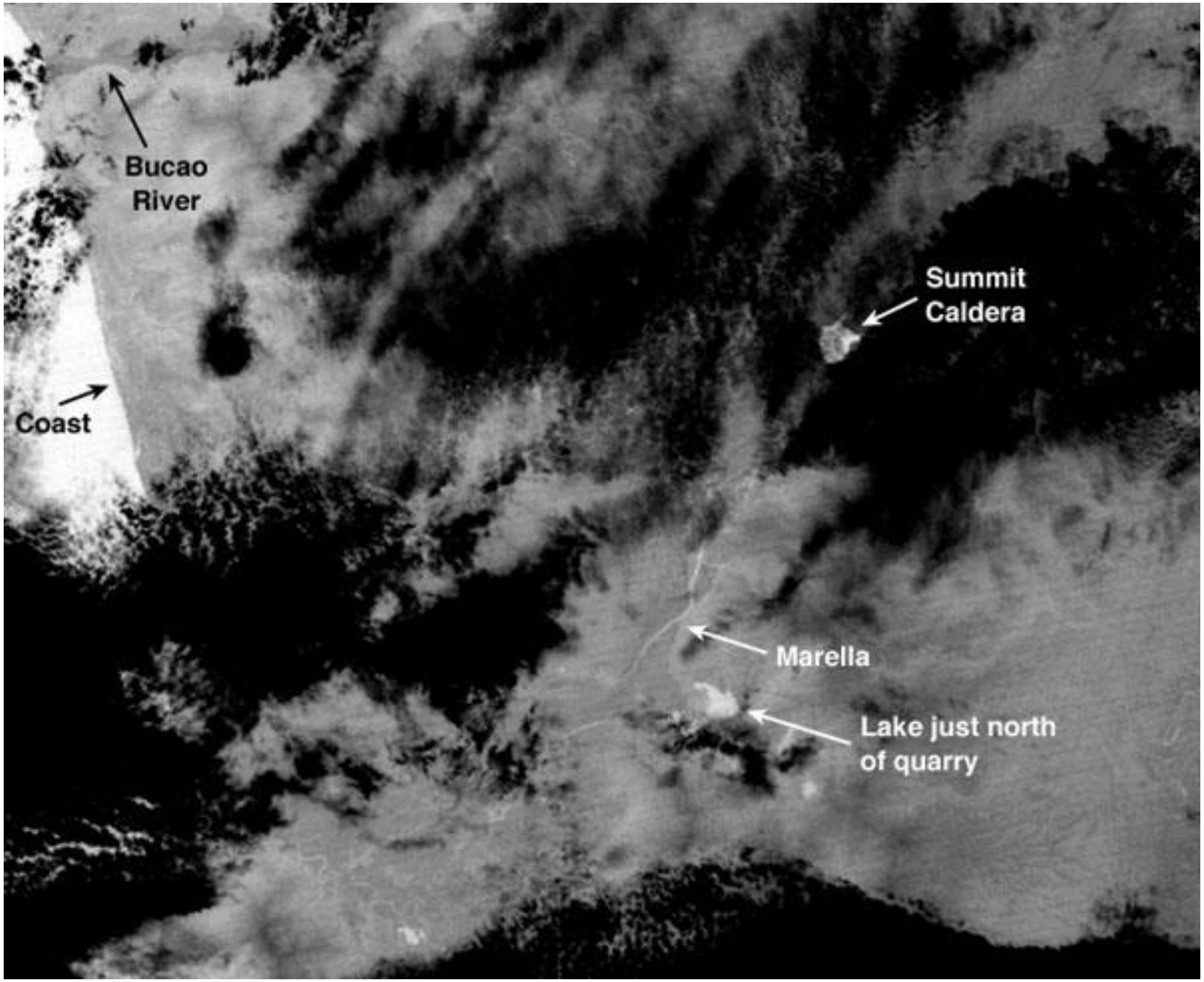
ERS-1 radar backscatter image of Pasig-Potrero River showing low-backscatter lahar deposits

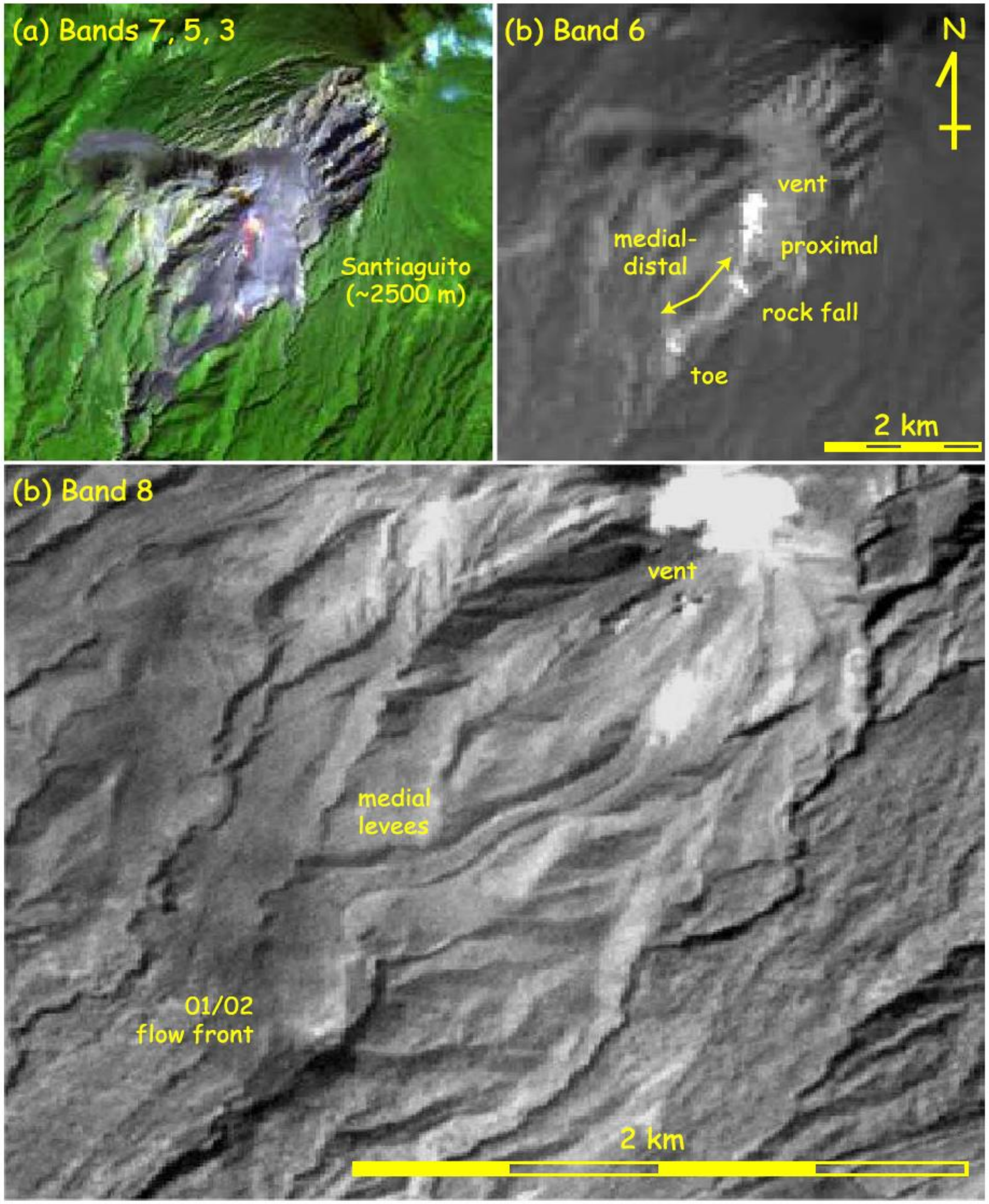


Shaded relief image of lahar fans SE of Mt. Pinatubo summit from NASA TOPSAR topographic data



Nighttime Landsat 7 thermal data
of Mt. Pinatubo shows warm streams

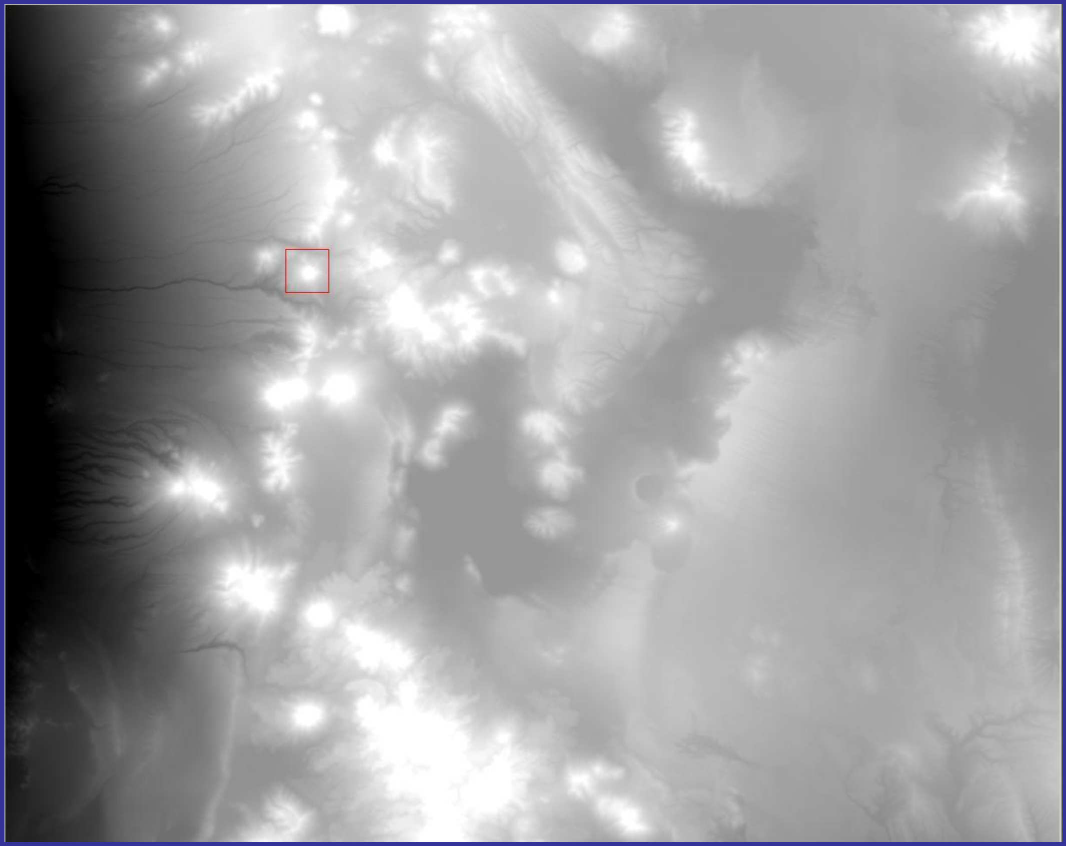




. (a) January 2000 band 7 (2.09–2.35 μm), 5 (1.55–1.75 μm), 3 (0.63–0.69 μm) ETM+ image, showing a thermal anomaly (yellow-
e colors) only at the vent and flow toe. (b) January 2000 band 6 (10.4–12.5 μm) ETM+ image of the same area showing a thermal
aly down the entire length of the active lava flow (lighter tones = higher temperatures). (c) January 2001 band 8 (0.52–0.90 μm) ETM+
of the active lava flow at Santiaguito. Shadows cast by the levees of the flow are readily apparent across the flow medial section.

SRTM Image

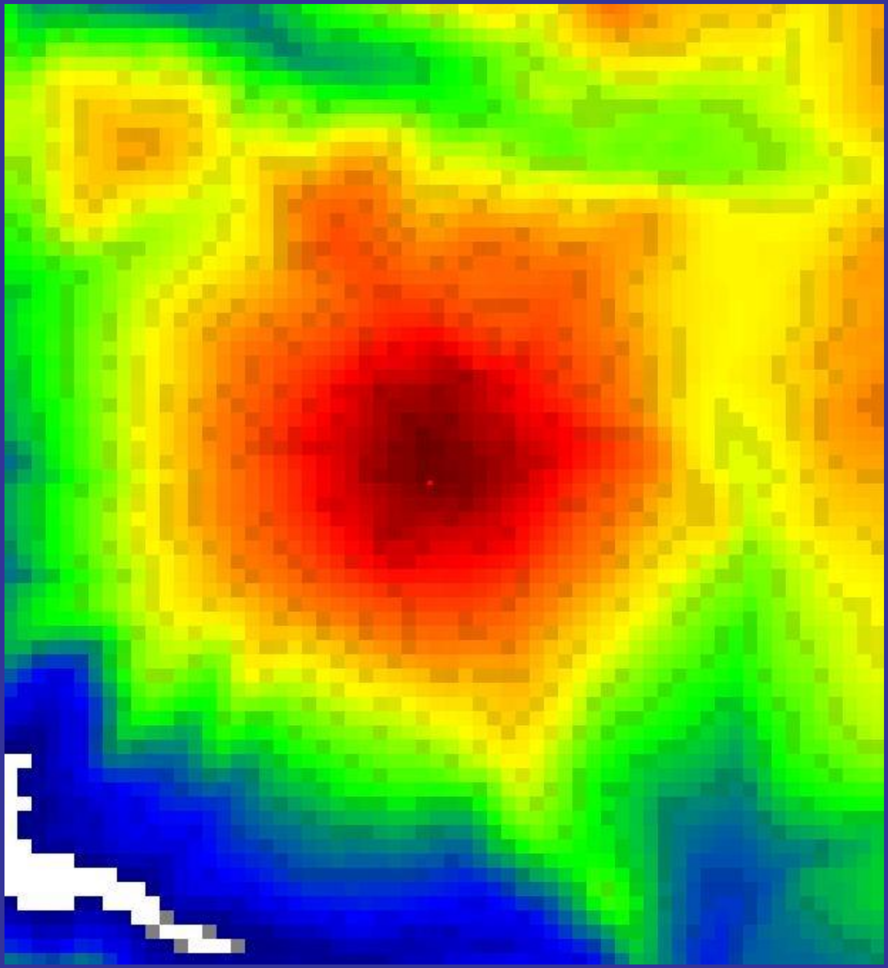
- SRTM Images come in 1 degree tiles.
- All images are grayscale.
- Images are opened with ENVI 4.1 geographic imaging software.
- ENVI allows geographic coordinates, allowing volcanoes to be found easily.
- This image is a tile 24 South, 68 West.



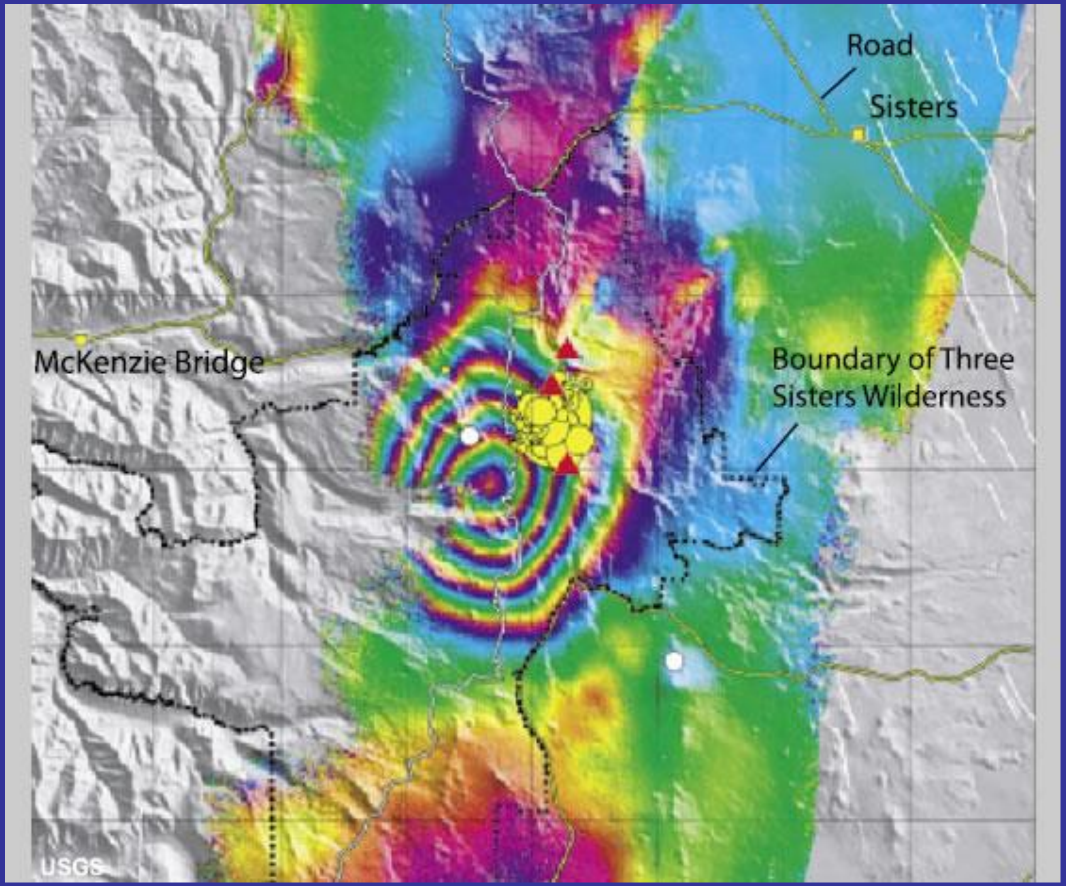
- Area in red box is Volcan Laguna Verde in Chile.

Color Image

- Used to show better detail.
- Allows for color saturation function to find semi-major and semi-minor axes of volcano in SigmaScan.
- Allows for more accurate geographic coordinates when switching between ENVI and SigmaScan.
- This image is a close up of Volcan Laguna Verde in Chile.



PERIODIC TOPOGRAPHIC DATA AND CAHNGES

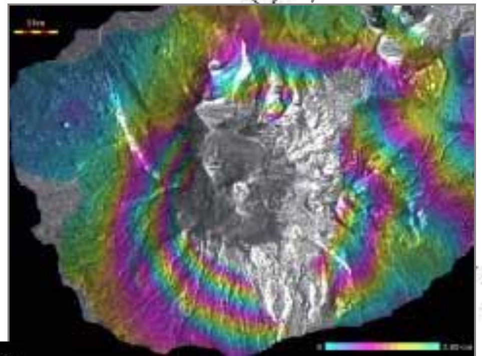


Scientists at the U.S. Geological Survey (USGS) use radar signals broadcast from a satellite to detect, measure and monitor small changes in the shape of Earth's surface. By bouncing the radar signal off of the surface, and detecting the return signal, they can make a very accurate topographic map. If they collect this information on multiple passes of the satellite they can compare them over time to detect change. The image above is a map of topographic change in the area surrounding Three Sisters Volcanoes (shown as red triangles). Colors on the map represent different degrees of elevation change. The bulls-eye pattern centered just southwest of the volcanoes is an area of uplift.

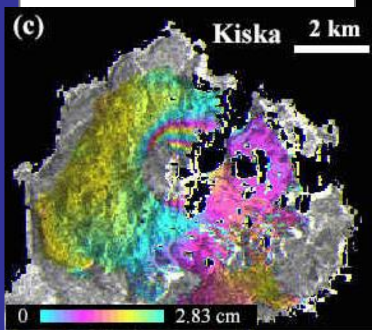
During a four year period (1997-2001) the area was lifted about 15 centimeters (6 inches). This uplift is thought to be caused by a magma intrusion. The yellow circles are epicenters of an earthquake swarm that could be associated with this motion. Image and caption adapted from USGS.

Alaska/Aleutians

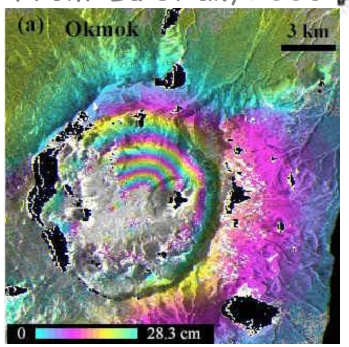
From: Lu et al., 2000

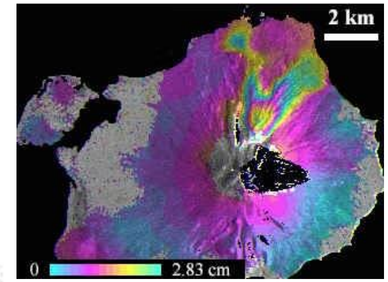


From: Lu et al., 2003



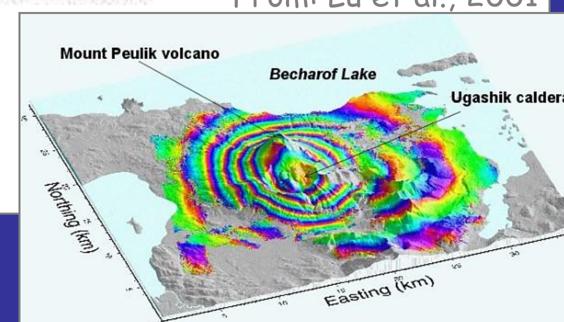
From: Lu et al., 2003

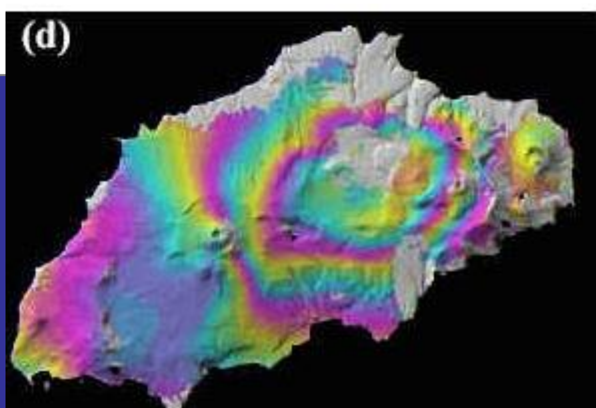




From: Lu et al., 2003

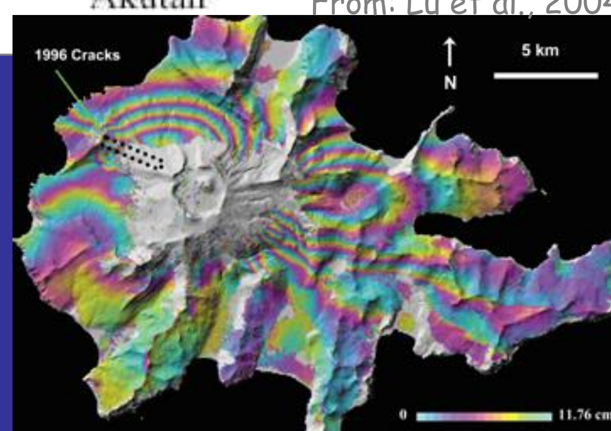
From: Lu et al., 2001



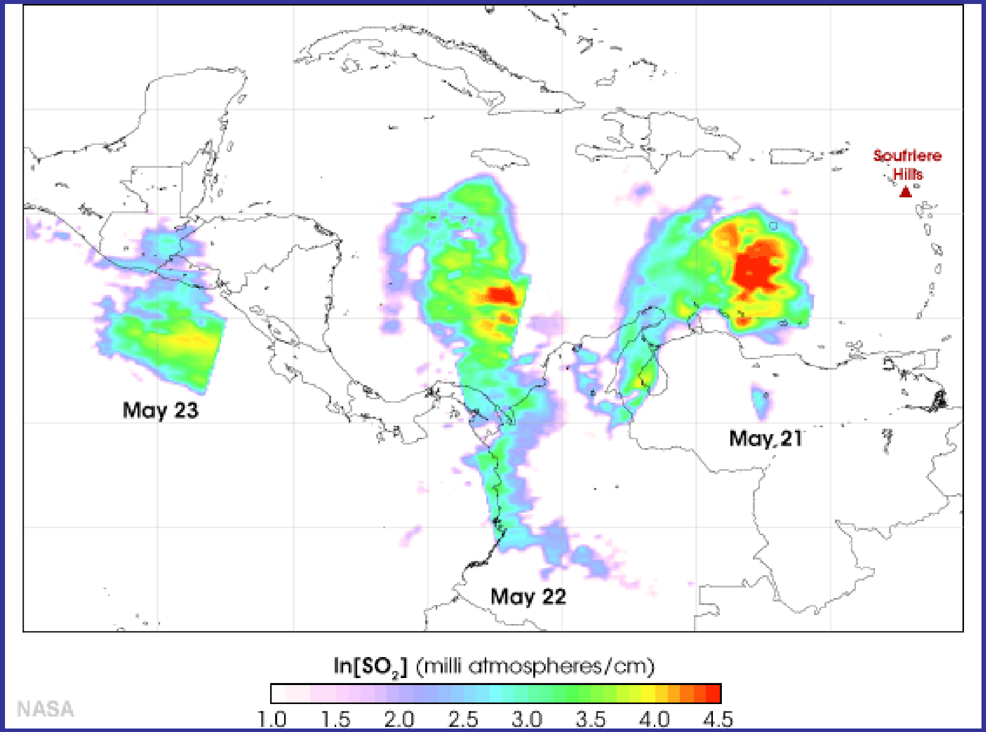


From: Lu et al., 2003

From: Lu et al., 2004



- 9 deforming volcanoes
- Subsiding pyroclastic flow
- Eruptions with no deformation
- Studies are ongoing



Soufriere Hills Volcano on Montserrat Island in the Caribbean produced an explosive eruption on the morning of May 20, 2006. This eruption sent about 90 million cubic meters of material down the slopes and into the atmosphere. Avalanches of mud and rock swept down stream channels and into the ocean. And, a cloud of ash and volcanic gas pushed up over 17 kilometers (55,000 feet) into the atmosphere. An infrared sounder on NASA's Aqua satellite was able to detect the cloud on three different passes over this region. Soufriere Hills Volcano can be seen on the above map, near the eastern margin.

About one day after the eruption on May 21, Aqua detected the ash cloud south of Puerto Rico, about 250 miles (400 kilometers) west of Montserrat Island. The following day, May 22, the cloud was south of Jamaica, about 1000 miles (1600 kilometers) west of Montserrat Island. The third day after the eruption the cloud was over San Salvador and its concentration and detectable size was significantly reduced.

The spaceborne moderate resolution imaging spectro radiometer (MODIS), which, from its synoptic perspective, provides satellite imagery of every volcano on Earth every 2 days.

MODIS has the spectral characteristics to be able to utilise previously developed retrievals that quantify volcanic ash, ice, sulfates and sulfur dioxide using their thermal infrared (8–12 Am) transmission signature.

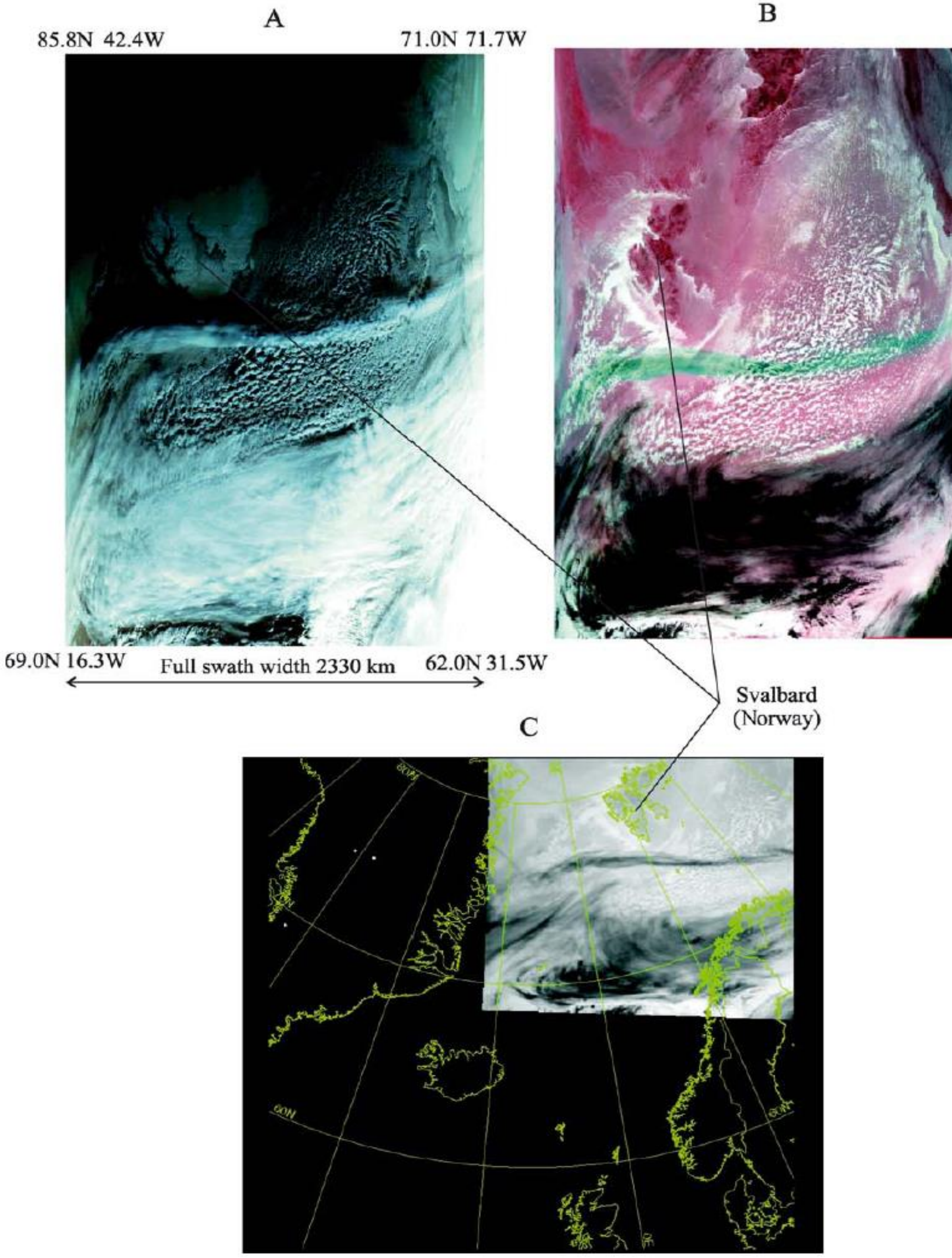
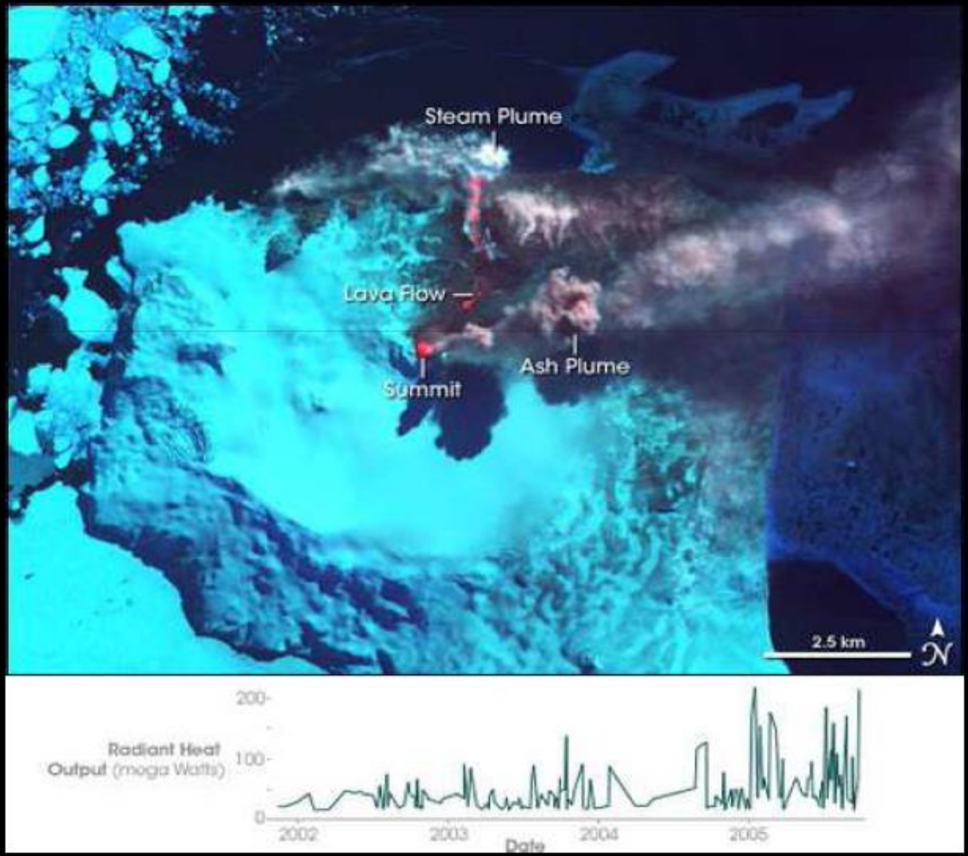


Fig. 2. (A) Channel [1], 0.62 – 0.67 μm, MODIS image of the Hekla eruption cloud, acquired at 1115 UT on 28 February 2000 at 250-m spatial resolution; (B) the same image as (A) using red – green – blue [28,31,32] composite at 1-km resolution; (C) the same image georeferenced—single channel [28]—showing location of SO_2 cloud relative to geographic boundaries.

MODVOLC

Algorithm created by University of Hawaii “The MODVOLC algorithm automatically scans each 1 kilometer pixel within it to check for the presence of high temperature hot-spots.” Used not only for volcanic eruptions, but wildfires as well.



Eruption first recorded using MODVOLC

ASTER

Advanced Spaceborne Thermal Emission and Reflection Radiometer Launched in 1999, part of NASA's EOS Spatial Resolution 15m(VNIR), 30m(SWIR), 90(TIR). 16 day temporal resolution possible

Thermal infrared band and DEM from ASTER very much for volcanoes study

Figure 3. A three dimensional perspective view created from an ASTER digital elevation model with a simulated natural color ASTER image. El Misti volcano towers above the city of Arequipa, Peru, with a population of more than one million. Geologic studies indicate that a major eruption occurred in the 15th century. Despite the obvious hazard, civil defense authorities see it as a remote danger, and development continues on the volcano side of the city.

Volcanic ash and aviation safety

- Many of the world's civil air routes cross active volcanoes
- Ash erupted by a volcano frequently reaches aircraft altitudes (9-12 km)
- Aircraft encounters with ash are potentially fatal
- Ash can clog engines, causing them to fail

Volcanic Ash

Volcanic Ash induce the Aviation hazards

"Ash clouds are not an everyday issue and they do not provide frequent hazard. But if encountered, volcanic ash can spoil your entire day." (Engen, 1994)

- **Between 1975 and 1994, more than 80 jet airplanes were damaged due to unplanned encounters with drifting clouds of volcanic ash.**
- **Seven of these encounters caused in-flight loss of jet engine power, .. Putting at severe risk more than 1,500 passengers.**
- **The repair and replacement costs associated with with airplane-ash cloud encounters are high and have exceeded $200 million. (Casadevall, 1994)**

How is the ash/aerosol plume, or dust distinguished on satellite imagery?

Use of multi-channel imagery:

- 10.7 um - 12.0 um temperature difference
- 8.5 um - 10.7 um temperature difference
- 3.9 um - 10.7 um radiance/temperature difference
- 3.9/10.7/12.0 um combined product

Ash/Dust in the 10.7 – 12.0 um range

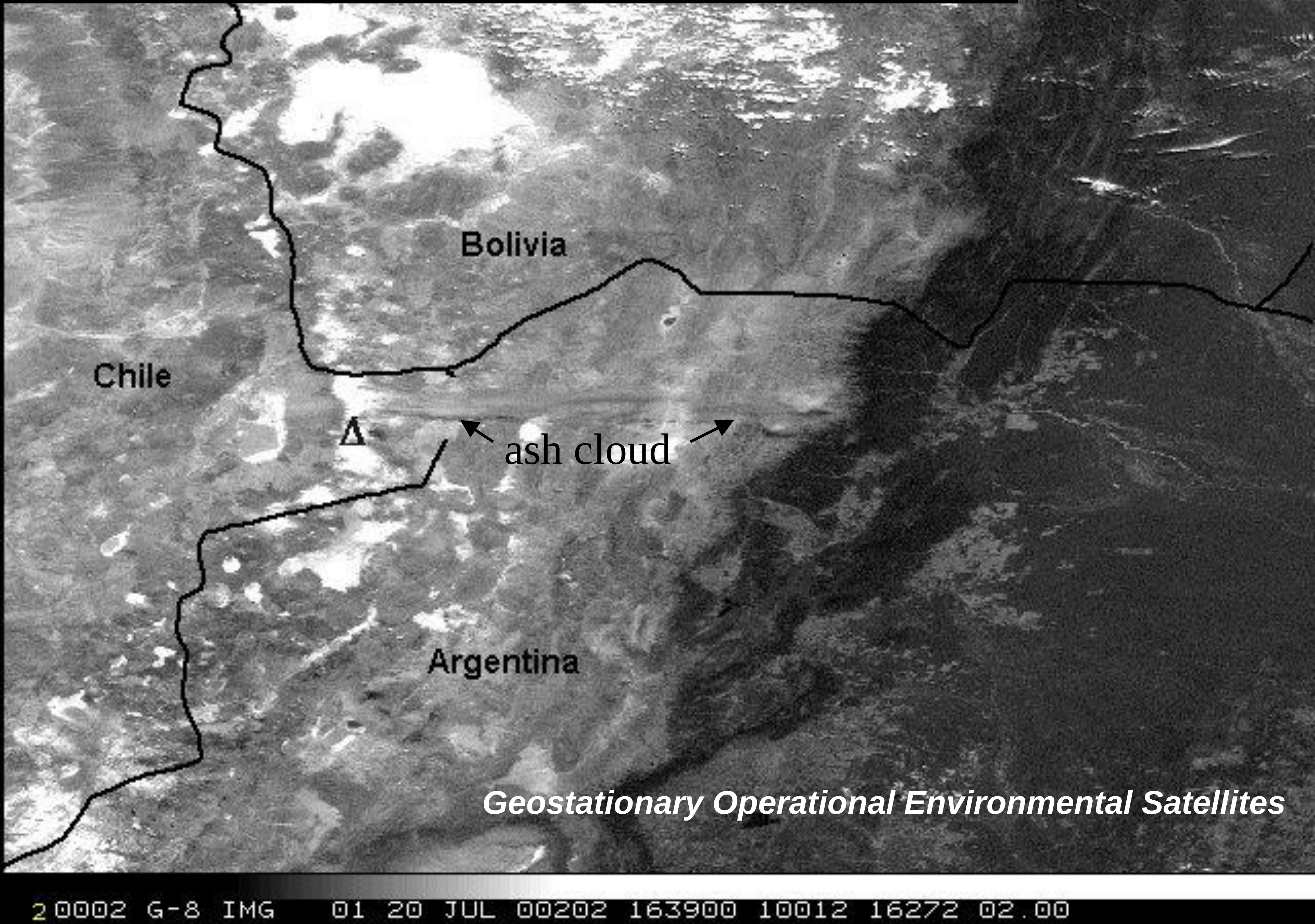
Silicates appear warmer at 10.7 um than at 12.0 um

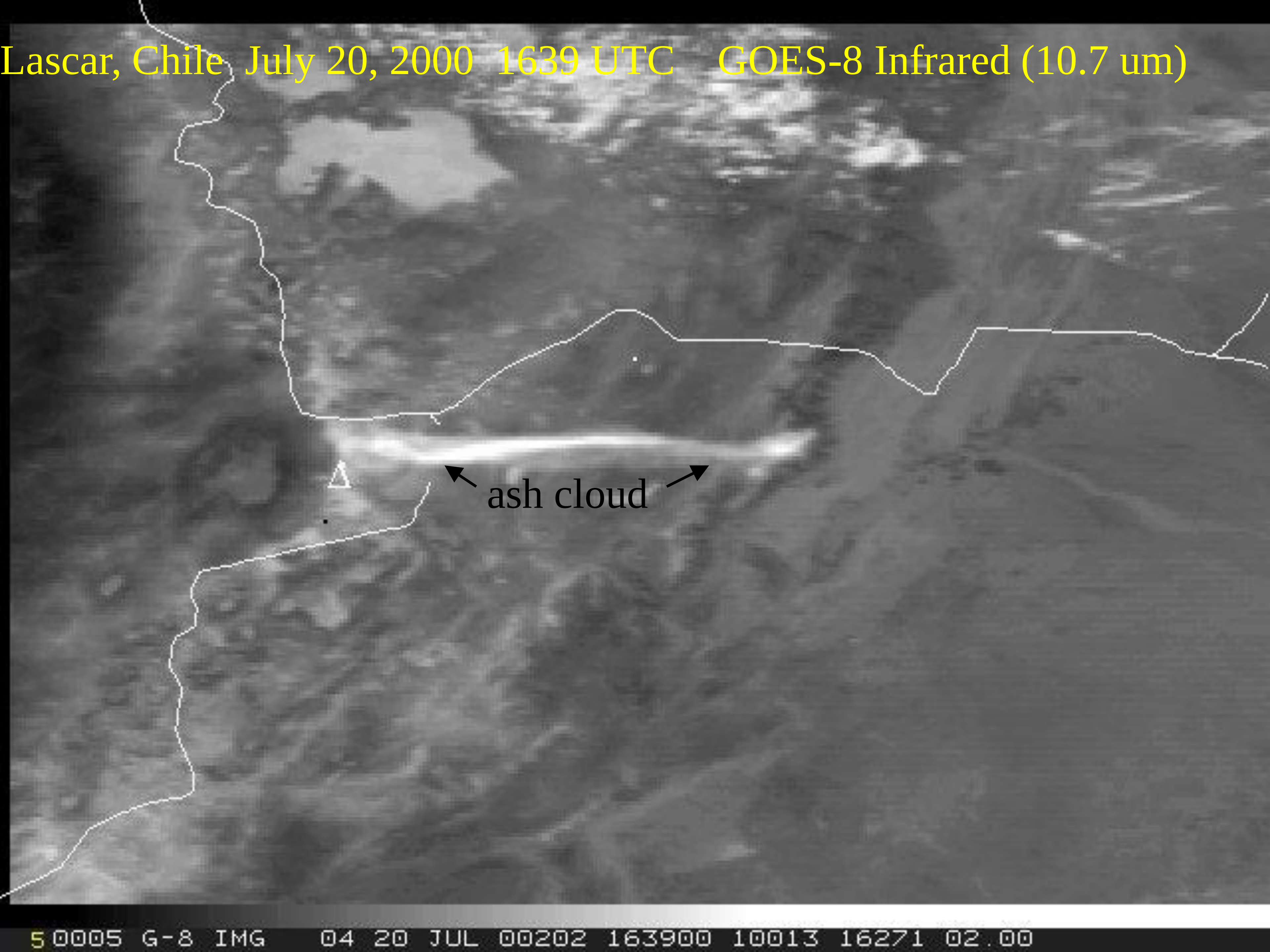
Water/ice particles appear warmer at 12.0 um than at 10.7 um

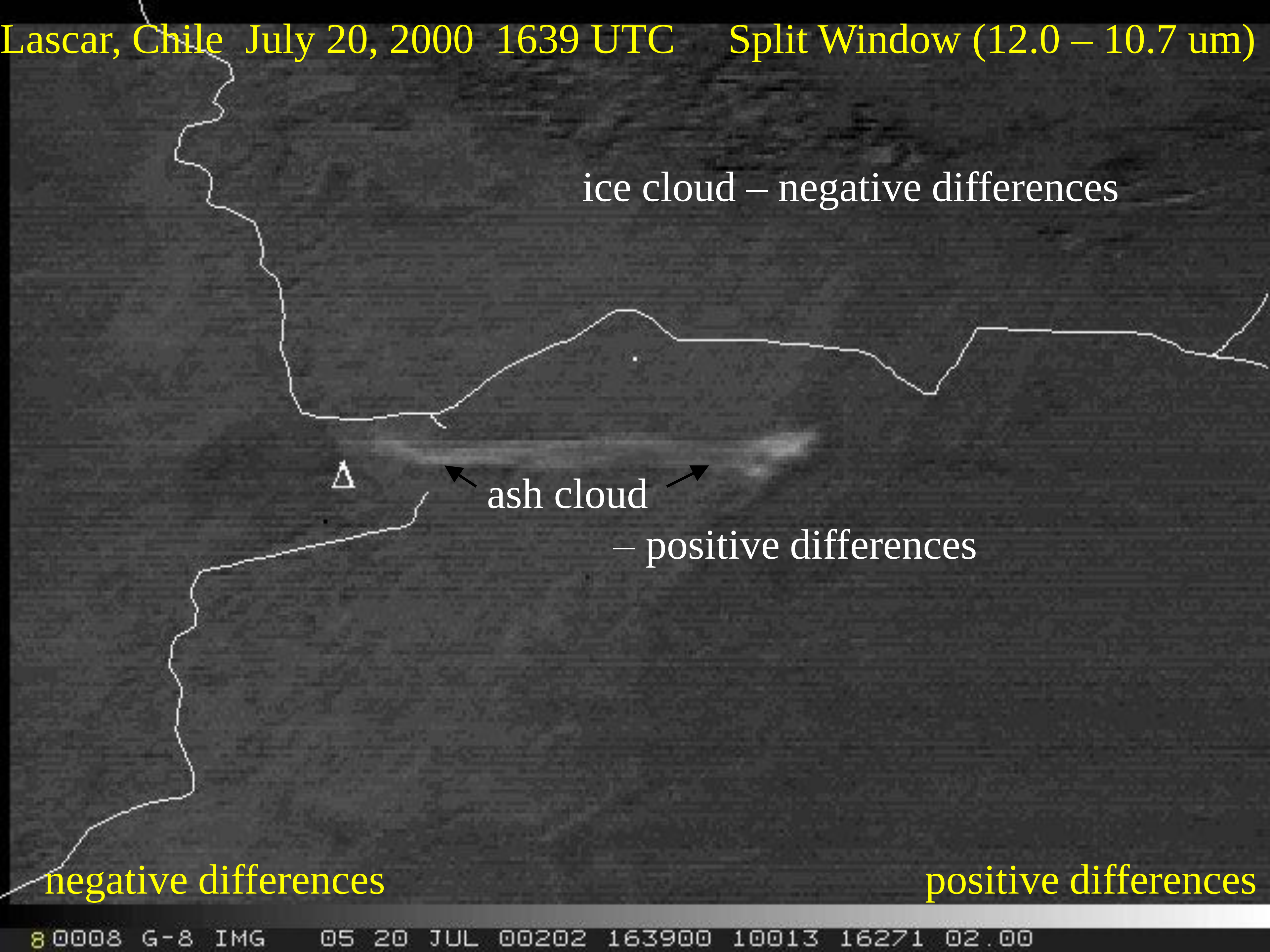
$BT_{12.0um}$-$BT_{10.7um}$ = positive for ash/dust

$BT_{12.0um}$-$BT_{10.7um}$ = negative for ice/water cloud

Lascar, Chile July 20, 2000 GOES-8 visible imagery



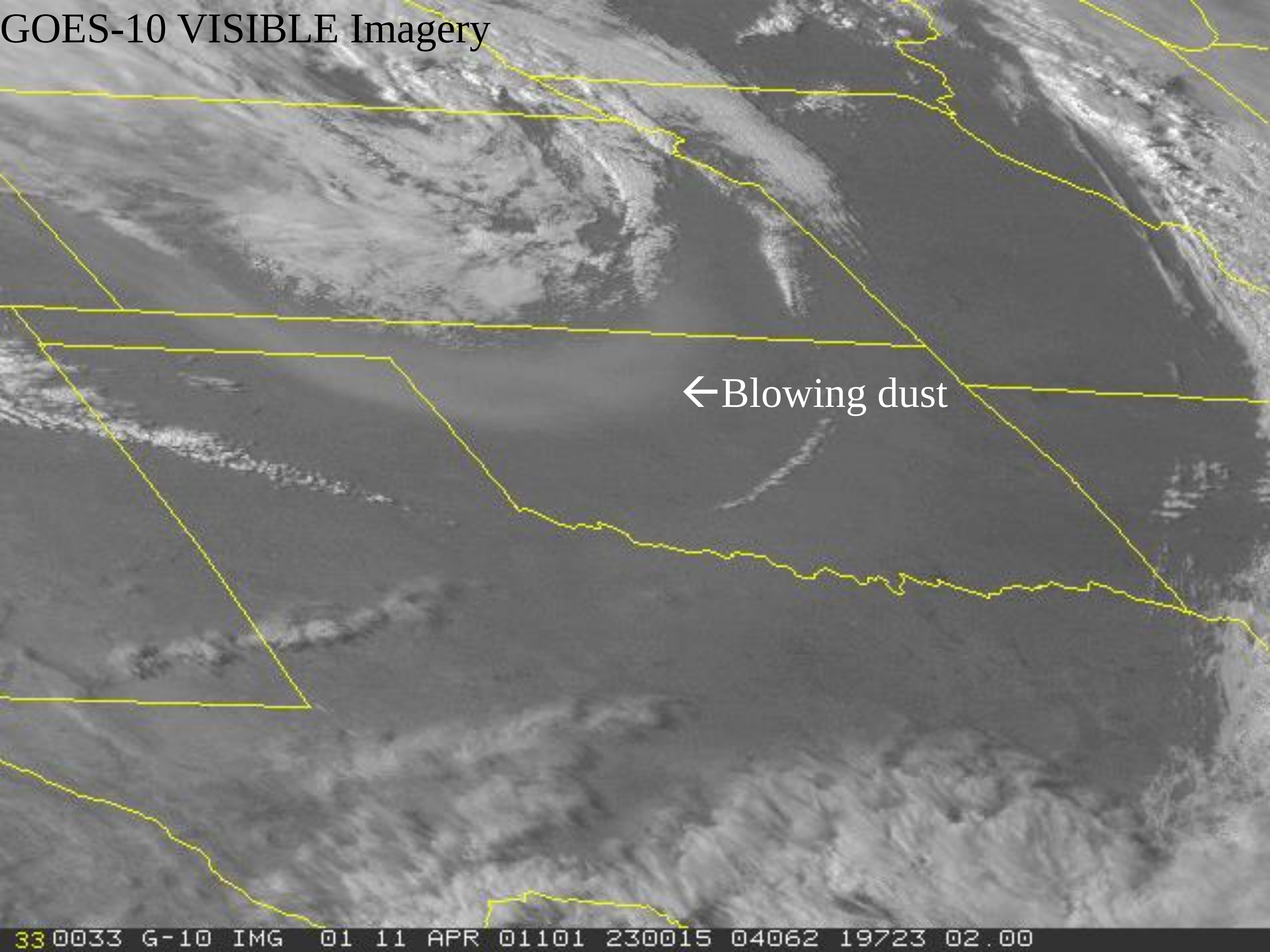

Lascar, Chile July 20, 2000 1639 UTC GOES-8 Infrared (10.7 um)
ash cloud
5 0005 G-8 IMG 04 20 JUL 00202 163900 10013 16271 02.00

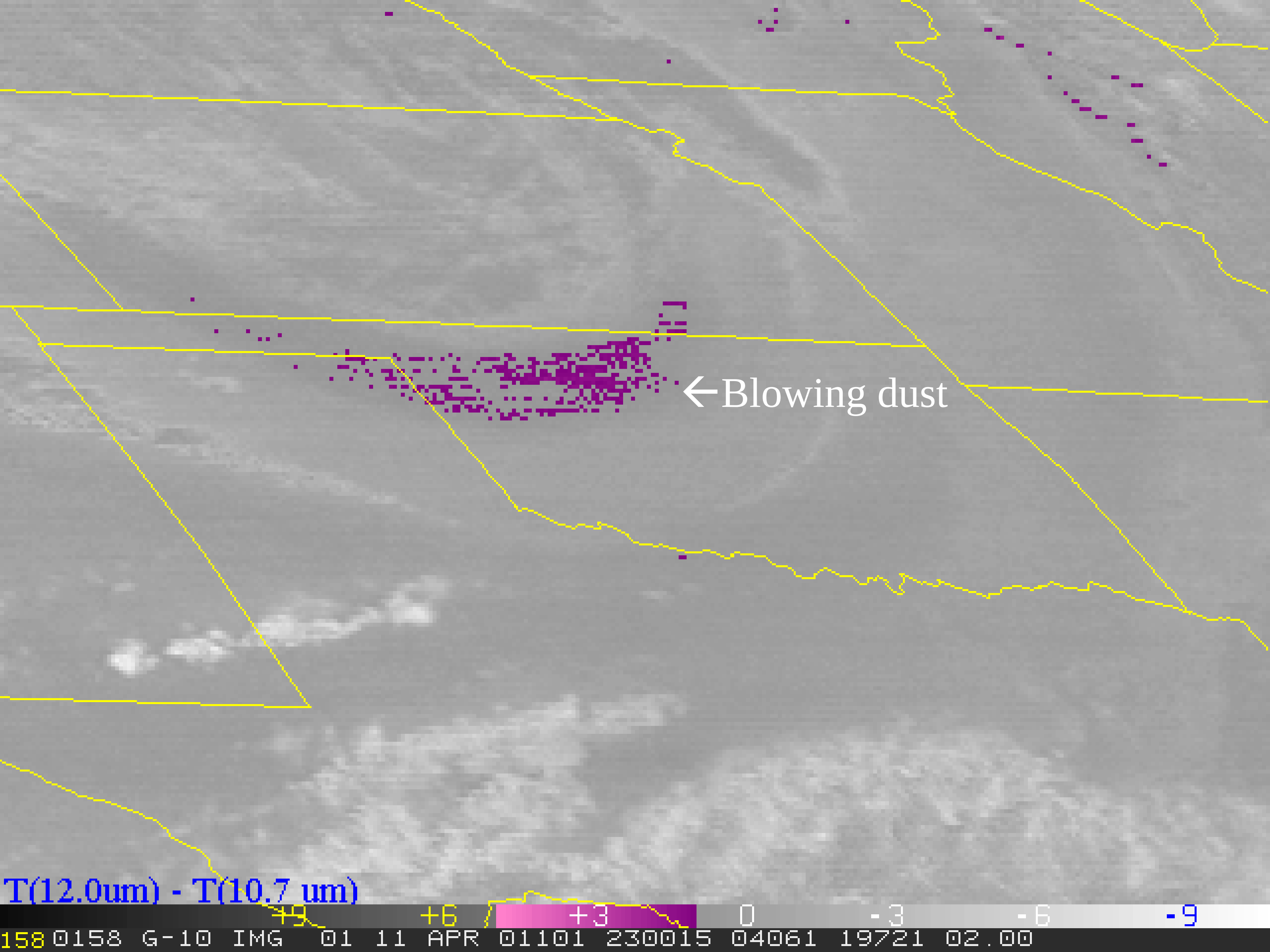

Lascar, Chile July 20, 2000 1639 UTC
Split Window (12.0 – 10.7 um)
ice cloud – negative differences
ash cloud
– positive differences
negative differences
positive differences
8 0008 G-8 IMG 05 20 JUL 00202 163900 10013 16271 02.00

Dust

Detection of "dust" is similar to ash.
Emissivity of many soil particles at 10.7 um is less than that at 12.0 um:

$$T(12.0um) - T(10.7um) > 0.0$$


GOES-10 VISIBLE Imagery
←Blowing dust
33 0033 G-10 IMG 01 11 APR 01101 230015 04062 19723 02.00



←Blowing dust
T(12.0um) - T(10.7 um)
+9 +6 +3 0 -3 -6 -9
158 0158 G-10 IMG 01 11 APR 01101 230015 04061 19721 02.00

3.9/10.7/12.0 Product

Experimental Volcanic Ash Product (Ellrod et al. 2001)

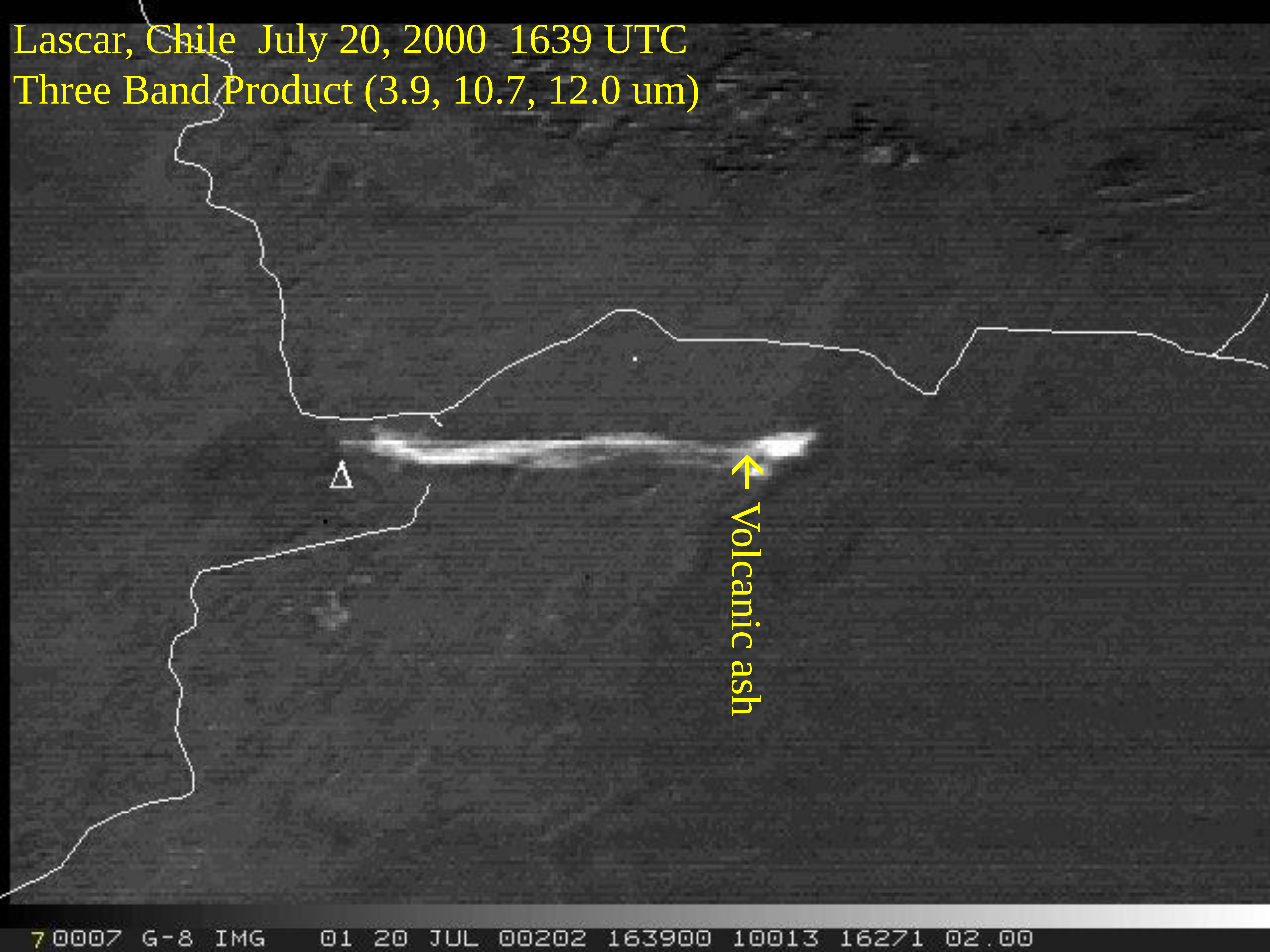
B=C + m [T(12.0)-T(10.7)]+[T(3.9)-T(10.7)]

B= output brightness value

C=constant=60 (determined empirically)

M=scaling factor=10 (determined empirically)

T= brightness temperature at (wavelength)



Lascar, Chile July 20, 2000 1639 UTC
Three Band Product (3.9, 10.7, 12.0 um)
Volcanic ash
7 0007 G-8 IMG 01 20 JUL 00202 163900 10013 16271 02.00

SO_2 detection

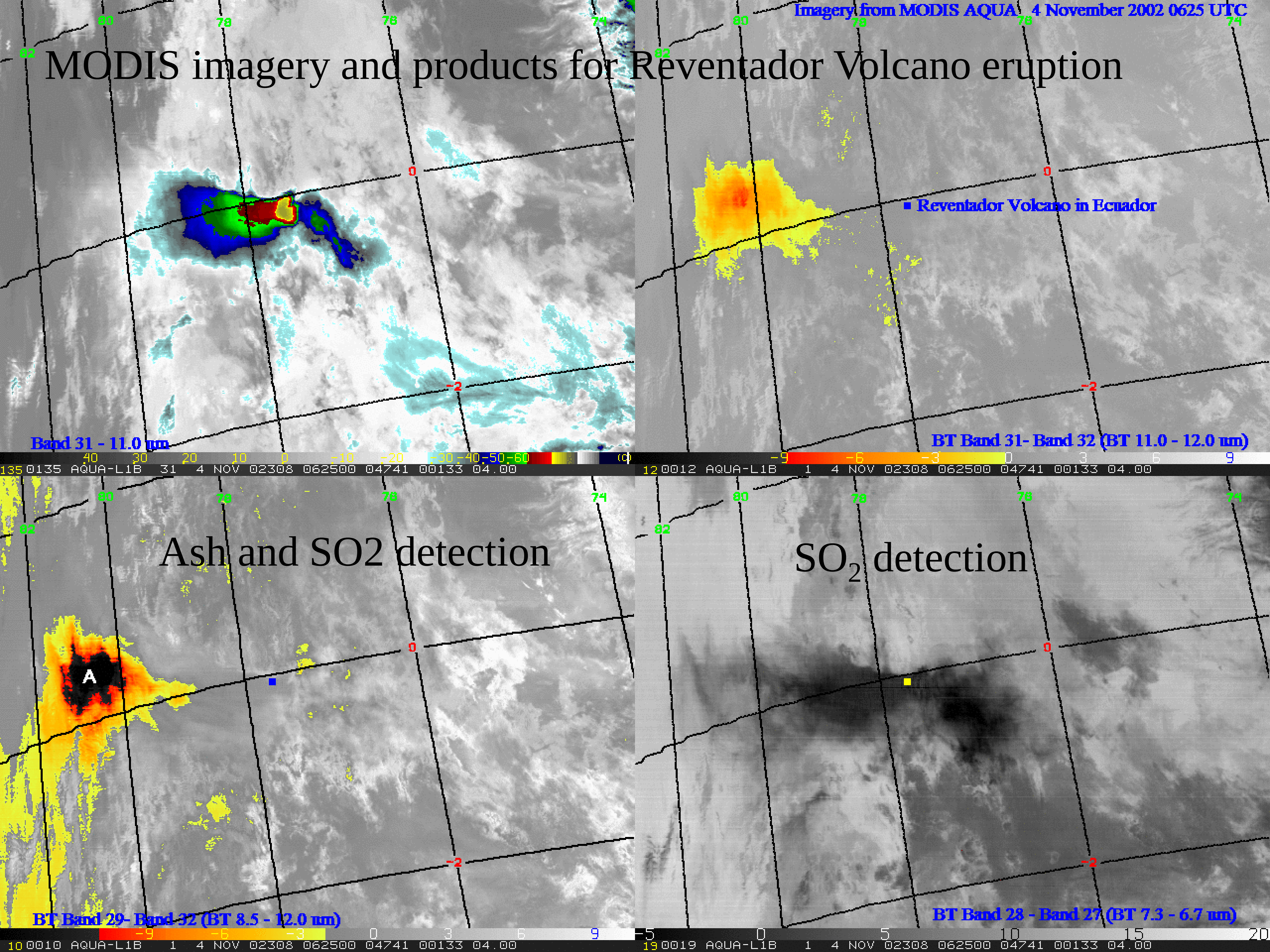
Greater SO_2 absorption at 7.3 um

BT 7.3 um – BT 6.7 um < 0

Less SO2 absorption at 8.5 um

Ash absorption at 8.5 um

BT 8.5 um – BT 12.0 um < 0


MODIS imagery and products for Reventador Volcano eruption
Imagery from MODIS AQUA 4 November 2002 0625 UTC
Band 31 - 11.0 μm
0135 AQUA-L1B 31 4 NOV 02308 062500 04741 00133 04.00
BT Band 31- Band 32 (BT 11.0 - 12.0 um)
Reventador Volcano in Ecuador
0012 AQUA-L1B 1 4 NOV 02308 062500 04741 00133 04.00
Ash and SO2 detection
A
BT Band 29- Band 32 (BT 8.5 - 12.0 um)
0010 AQUA-L1B 1 4 NOV 02308 062500 04741 00133 04.00
SO$_2$ detection
BT Band 28 - Band 27 (BT 7.3 - 6.7 um)
0019 AQUA-L1B 1 4 NOV 02308 062500 04741 00133 04.00

DROUGHT

Drought is considered by many to be the most complex but least understood of all natural hazards, affecting more people than any other hazard (G.Hagman 1984).

Droughts have no universal definition. As drought definitions are region specific, reflecting differences in climatic characteristics as well as incorporating different physical, biological and socio-economic variables, it is usually difficult to transfer definitions derived for one region to another

However some of the common definitions for drought

The Director of Common Wealth Bureau of Meteorology in 1965 suggested a broad definition of drought as “severe water shortage”.

Definition given by Palmer states that “Drought is an interval of time, generally of the order of months of years in duration, during which the actual moisture supply at a given place rather consistently falls short of the climatically expected or climatically appropriate moisture supply (Palmer, 1965)

According to Mc Mohan and Diaz Arena (1982), “Drought is a period of abnormally dry weather sufficiently for the lack of precipitation to cause a serious hydrological imbalance and carries connotations of a moisture deficiency with respect to man’s usage of water

By studying the above definitions it can be understood that drought is mainly concerned with the shortage of water which in turn affects availability of food and fodder thereby leading to displacement and loss to economies as a whole.

Droughts can be classified in four major categories:

- Meteorological drought
- Hydrological drought
- Agricultural drought
- Socio-economic drought

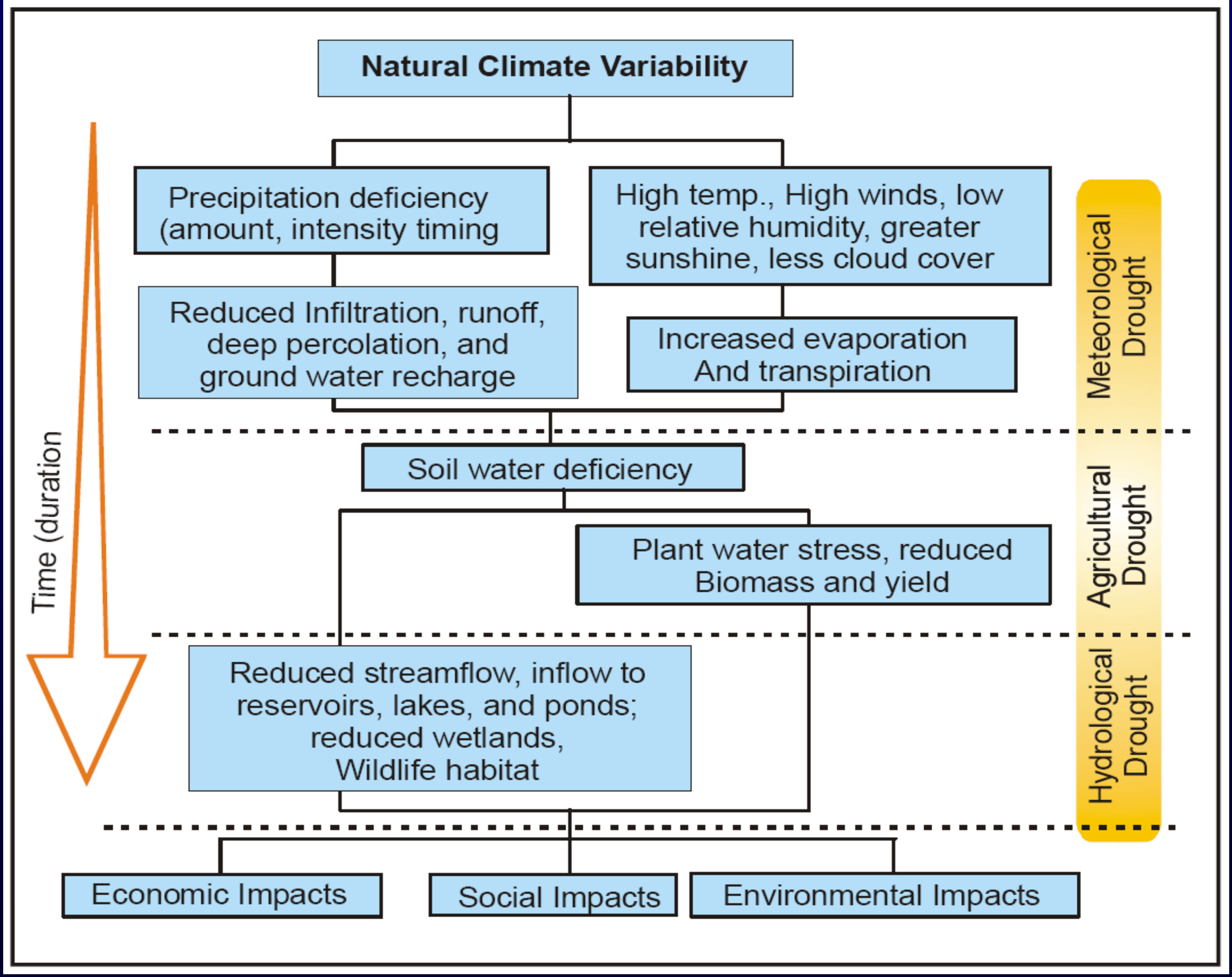
Meteorological drought: it simply implies rainfall deficiency where the precipitation is reduced by more than 25%from normal in any given area. These are region specific, since deficiency of precipitation is highly variable from region to region.

Hydrological drought: these are associated with the deficiency of water on surface or subsurface due to shortfall in precipitation. Although all droughts have their origination from deficiency in precipitation, hydrological drought is mainly concerned about how this deficiency affects components of the hydrological system such as soil moisture, stream flow, ground water and reservoir levels etc

Agricultural drought: this links various characteristics of meteorological or hydrological drought to agricultural impacts, focusing on precipitation shortages, differences between actual potential evapotranspiration, soil, soil water deficits, and reduced ground water or reservoir levels. Plant water demand depends on prevailing weather conditions, biological characteristics of the specific plant, and its stage of growth and the physical and biological properties of the soil.

Socio-economic drought: it is associated with the demand and supply aspect of economic goods together with elements of meteorological, hydrological and agricultural drought. This type of drought mainly occurs when there the demand for an economic good exceeds its supply due to weather related shortfall in water supply

A relationship between the meteorological, agricultural and hydrological droughts



Economic impacts

Many economic impacts occur in agriculture and related sectors, including forestry and fisheries, because of the dependence of these sectors on surface and subsurface water supplies.

In addition to obvious losses in yields in crop and livestock production, drought is associated with increases in insect infestations, plant disease, and wind erosion. Droughts also bring increased problems with insects and diseases to forests and reduce growth.

The incidence of forest fires increases substantially during extended droughts, which in turn places both human and wildlife populations at higher levels of risk.

Environmental Impacts

Environmental losses are the result of

- ❖ Damages to plant and animal species, wildlife habitat, and air and water quality
- ❖ Forest and range fires
- ❖ Degradation of landscape quality;
- ❖ Loss of biodiversity and
- ❖ Soil erosion

Social Impacts

- Social impacts involve public safety, health, conflicts between water users, reduced quality of life, and inequities in the distribution of impacts and disaster relief.
- Population migration is a significant problem in many countries, often stimulated by a greater supply of food and water elsewhere.
- Migration is usually to urban areas within the stressed area, or to regions outside the drought area. Migration may even be to adjacent countries.
- The drought migrants place increasing pressure on the social infrastructure of the urban areas, leading to increased poverty and social unrest.

History of droughts in India and Gujarat

Agriculture in India is often seen as a gamble on summer monsoon rainfall. Summer monsoon rains constitute the greatest climatic resource of the Indian subcontinent as these rains support not only the country's agriculture and food production but substantially contribute to power generation (H.P.Das 2000).

Thus success or failure of the crops and economy are intimately linked with prospects of good or bad monsoon

The Indian subcontinent is predominantly characterized by a tropical monsoon climate, where climatic regimes are governed by the differences in rainfall, rather than temperatures.

There are two monsoon systems operating in the region- the southwest or summer monsoon and the northeast or the winter monsoon.

The summer monsoon accounts for 70 to 90 percent of the annual rainfall over major parts of South Asia (Krishnamurthy and Shukla, 2000).

There is a large variability in the monsoon rainfall on both space and time scales.

some part of the country or the other almost every year during the monsoon period (June-September).

The drought of 1987 was one of the worst in the century. The monsoon rainfall was normal only in 14 out of 35 meteorological sub-divisions in the country. The overall deficiency in rainfall was 19% as compared to 26% in 1918 and 25% in 1972 being worst years.

Agricultural operations were adversely affected in 43% (58.6 million ha) of cropped area in 263 districts in 15 States and 6 Union Territories.

In the two worst affected states of Rajasthan and Gujarat, the rainfall was less than 50% from normal.

In these states, the drought of 1987 was the third or fourth in succession resulting in distress to an unprecedented level. Gujarat is one such state where drought occurs with unfailing regularity

1901-1910	1911-1920	1921-1930	1931-1940	1941-1950	1951-1960	1961-1970	1971-1980	1981-1990	1991-2000
Gujarat state									
1901	1911	1923	1931	1942	1951	1962	1972	1982	1991
1904	1915	1924	1936	1948	1952	1963	1973	1985	1993
1905	1918	1925	1938		1955	1965	1974	1986	1995
	1920	1927	1939		1957	1966		1987	1998
		1929	1940		1960	1968		1990	1999
									2000
All India									
1901	1911			1941	1951	1965	1972	1982	
1904	1918					1966	1974	1987	
1905	1920					1968	1979		

Table 1-1 All India and Gujarat state Drought Years

(Source: Gore and Ponkshe, 2004)

The monsoon of 2000 was the 13th consecutive normal monsoon considering country as a whole, but on a regional basis, this was the third consecutive drought year in areas covered by the states of Rajasthan, Gujarat and Andhra Pradesh

In 1999, as many as 98 out of a total of 225 blocks in the state received less than 50% of the season's expected rainfall. In 1999, Gujarat faced the worst drought of the past 100 years. Some 7,500 villages spread over 145 blocks in 15 districts were severely affected. The state has been hit by the worst drought in 100 years. More than 25 million people living in 9,000 villages of 17 of the 25 districts have been hit.

Almost all water sources have dried up; there is no food for the people and no fodder for over 7 million cattle. The water table in drought affected Saurashtra, Kutch and northern Gujarat is said to be falling by 10-15 feet each year (Bavadam 2001).

Drought risk evaluation

Risk assessment involves evaluation of the significance of a risk, either quantitatively or qualitatively.

Risk assessment/evaluation according to Kates and Kasperson (1983) comprises of three steps:

- Identification of hazards, which may cause disasters.
- Estimation of risks arising out of such events and
- Estimation of losses

Meteorological drought indices and drought detection

Drought indices have been developed as a means to measure drought. A drought index assimilates thousands of data on rainfall, snow pack, stream flow and other water-supply indicators into a comprehensible picture.

There are several indices that measure how much precipitation for a given period of time has deviated from historically established norms.

Some of the widely used drought indices include Palmer Drought Severity Index (PDSI), Crop Moisture Index (CMI), Standardized Precipitation Index (SPI), and Surface Water Supply Index (SWSI).

Palmer Drought Severity Index (PDSI)

In 1965, W.C. Palmer developed an index to measure the departure of the moisture supply (Palmer,1965).

The Palmer Drought Severity Index (PDSI) is to provide standardized measurements of moisture conditions so that comparison could be made between locations and between months.

The PDSI is a meteorological drought index that is responsive to abnormal weather conditions either on dry or abnormally wet side.

The index was specifically designed to treat the drought problem in semiarid and sub humid climates; with palmer himself cautioning that extrapolation beyond these conditions may lead to unrealistic results.

Crop Moisture Index (CMI).

Three years after the introduction of his drought index, Palmer (1968) introduced a new drought index based on weekly mean temperature and precipitation known as Crop Moisture Index (CMI). It was specifically designed as an agricultural drought index

It measures both evapotranspiration deficits (drought) and excessive wetness (more than enough precipitation to meet evapotranspiration demand and recharge the soil).

CMI is designed to monitor short-term moisture conditions affecting a developing crop; therefore CMI is not a good long-term drought-monitoring tool.

Standardized Precipitation Index (SPI)

Tom Mckee, Nolan Doesken and John Kleist of the Colorado Climate Centre formulated the SPI in

The purpose is to assign a single numeric value to the precipitation that can be compared across

SPI Values	
2.0+	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
-.99 to .99	Near normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
-2 and less	Extremely dry

Table 2-1 Standardised Precipitation Index

Surface Water Supply Index (SWSI)

Shafer and Dezman (1982) to complement the Palmer Index for moisture conditions developed the Surface Water Supply Index (SWSI).

This index compliments the Palmer index for moisture condition.

It is dependent on the season; SWSI is computed with only snowpack, precipitation, and reservoir storage in the winter. During the summer months, stream flow replaces snowpack as a component within the SWSI equation.

Satellite based drought indices for drought characterization

Drought indicators assimilate information on rainfall, stored soil moisture or water supply but do not express much local spatial detail. Also, drought indices calculated at one location is only valid for single location. Thus, a major drawback of climate based drought indicators is their lack of spatial detail as well as they are dependent on data collected at weather stations which sometimes are sparsely distributed affecting the reliability of the drought indices (Brown and Reed et al., 2002)

Satellite derived drought indicators calculated from satellite-derived surface parameters have been widely used to study droughts. Normalized Difference Vegetation Index (NDVI), Vegetation Condition Index (VCI), and Temperature Condition Index (TCI) are some of the extensively used vegetation indices.

Normalized Difference Vegetation Index (NDVI)

Tucker first suggested NDVI in 1979 as an index of vegetation health and density

NDVI is defined as: **NDVI= (NIR-RED)/ (NIR+RED)**

Where, NIR and RED are the reflectance in the near infrared and red bands.

NDVI is a good indicator of green biomass, leaf area index, and patterns of production (Thenkabail and Gamage et al. 2004, Wang and Wang et al. 2004).

NDVI is the most commonly used vegetation index. It varies from +1 to -1. Since climate is one of the most important factors affecting vegetation condition, AVHRR- NDVI data have been used to evaluate climatic and environmental changes at regional and global scales

It can be used not only for accurate description of continental land cover, vegetation classification and vegetation strength but is also effective for monitoring rainfall and drought, estimating net primary production of vegetation, crop growth conditions and crop yields, detecting weather impacts and other events important for agriculture, ecology and economics (Singh &Roy et al. 2003).

NDVI has been used successfully to identify stressed and damaged crops and pastures but only in homogenous terrain. In more heterogeneous terrain regions their interpretation becomes more difficult (Vogt et al. 1998; Singh et al.2003).

Many studies in the Sahel Zone (Tucker et al 2005), Argentina (Sullivan et al.1998), SouthAfrica (Unganani & Kogan, 2004) and Mediterranean (Vogt et al., 1998), and Senegal (Li. et al.,2004) indicate meaningful direct relationships between NDVI derived from NOAA AVHRR satellites, rainfall and vegetation cover and biomass.

Vegetation Condition Index (VCI)

It was first suggested by Kogan (1997) (Thenkabail et al.2004; Vogt et al. 1998).

VCI is an indicator of the status of the vegetation cover as a function of the NDVI minimum and maxima encountered for a given ecosystem over many years.

VCI is defined as:

$$VCIj = (NDVIj - NDVImin) / (NDVImax - NDVImin) * 100$$

Where, NDVImax NDVImin is calculated from long-term record for a particular month and j is the index of the current month. The condition of the ground vegetation presented by VCI is measured in percent.

The VCI values between 50% to 100% indicate optimal or above normal conditions whereas VCI values close to zero percent reflects an extreme dry month.

VCI has been used by (Kogan and Unganani) for estimation of corn yield in South Africa; drought detection in Argentina (Sullivan et al 1998); drought monitoring over India (Singh et al.2002); monitoring droughts in the southern Great Plains, USA (Wan et al.2004); drought detection and monitoring in the Mediterranean region (Vogt et al.2000) and drought assessment and monitoring in Southwest Asia (Thenkabail et al. 2004).

These studies suggest that VCI captures rainfall dynamics better than the NDVI particularly in geographically non-homogeneous areas. Also, VCI values indicate how much the vegetation has advanced or deteriorated in response to weather.

It was concluded from the above studies that VCI has provided an assessment of spatial characteristics of drought, as well as its duration and severity and were in good agreement with precipitation patterns.

Temperature Condition Index (TCI)

TCI was also suggested by Kogan (1997), (Thenkabail et al. 2004). It was developed to reflect vegetation response to temperature i.e. higher the temperature the more extreme the drought.

TCI is based on brightness temperature and represents the deviation of the current month's value from the recorded maximum. TCI is defined as:

$$TCIj= (BT\ max- BTj)/ (BTmax- Btmin) *100$$

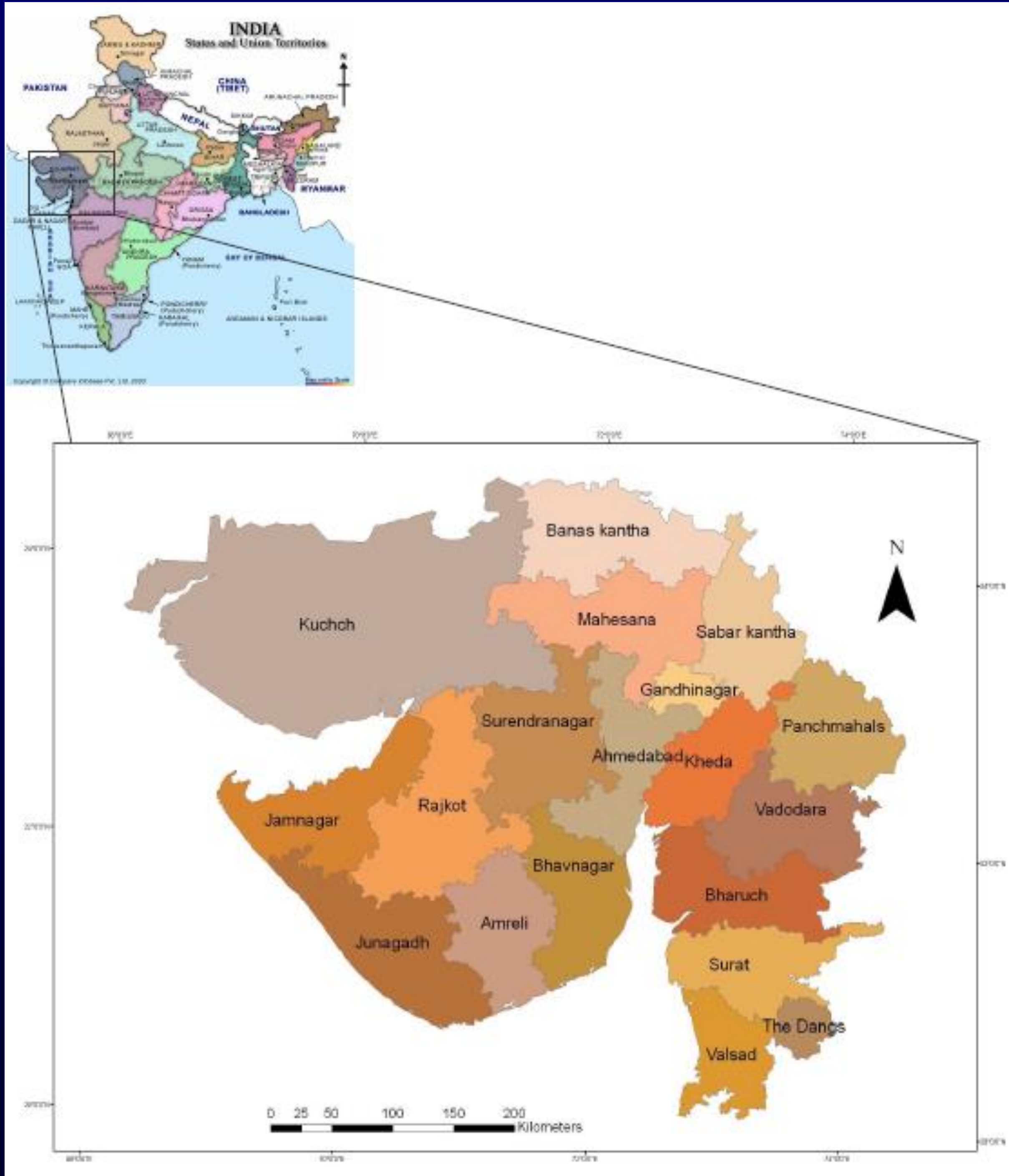
Where BT is brightness temperature. Maximum and minimum BT values are calculated from the long-term record of remote sensing images for a particular period j

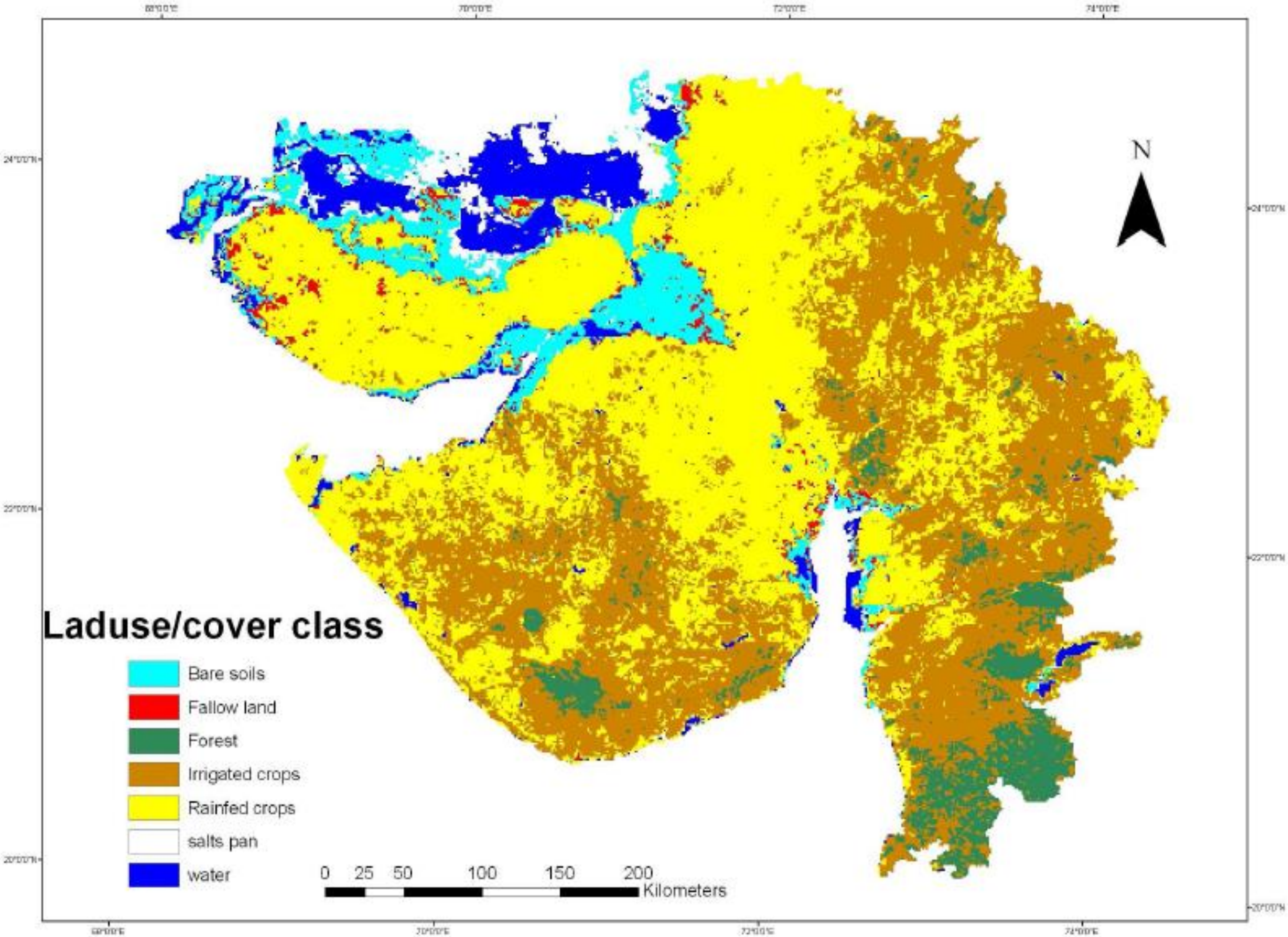
Low TCI values indicate very hot weather.

TCI has been used for drought monitoring in the USA, China, Zimbabwe and the Former Soviet Union.

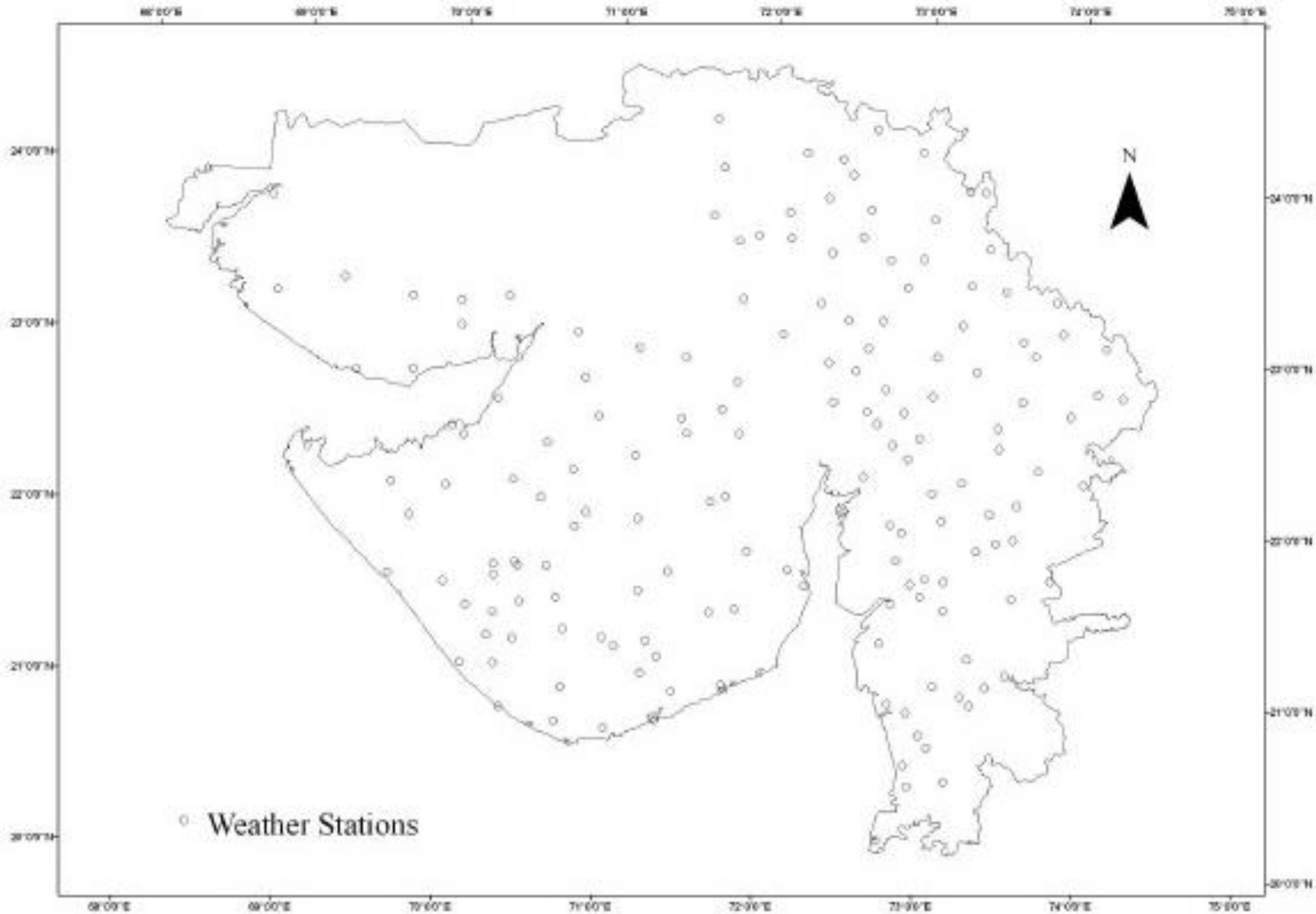
A study in Argentina for drought detection revealed that TCI was useful to assess the spatial characteristics, the duration and severity of droughts, and were in good agreement in precipitation patterns (Seiler et al.1998).

TCI has been related to recent regional scale drought patterns in South Africa (Kogan, 1998).


INDIA
States and Union Territories
PAKISTAN
CHINA (TIBET)
NEPAL
BHUTAN
MYANMAR
BANGLADESH
N
Banas kantha
Kuchch
Mahesana
Sabar kantha
Gandhinagar
Surendranagar
Panchmahals
Ahmedabad
Kheda
Rajkot
Jamnagar
Vadodara
Bhavnagar
Bharuch
Amreli
Junagadh
Surat
The Dangs
Valsad
0 25 50 100 150 200
Kilometers

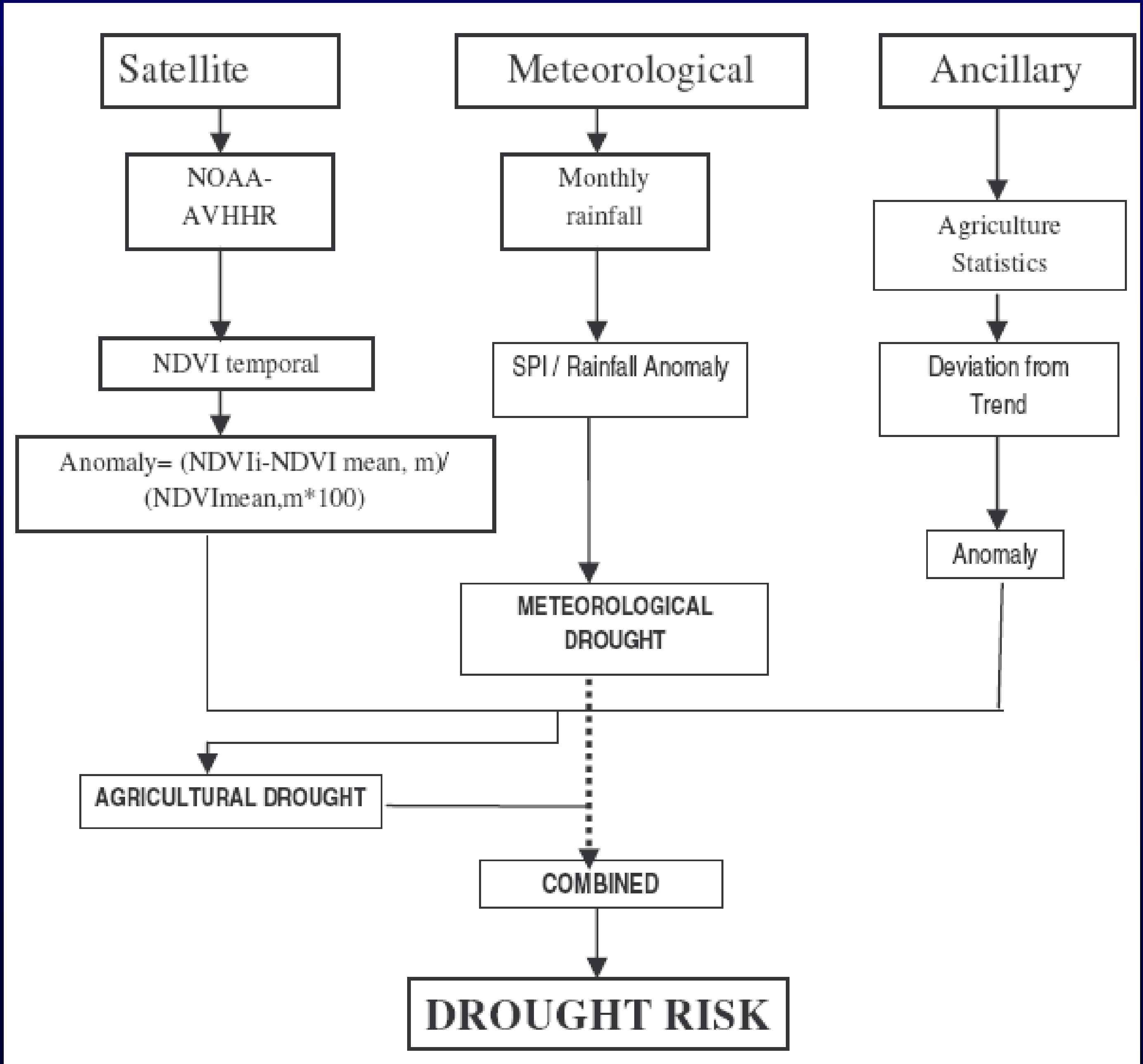


Generalised Landuse/cover map of Gujarat



Location of 164 weather stations in Gujarat

METHODOLOGY



RAINFALL vs NDVI (1981-2000)

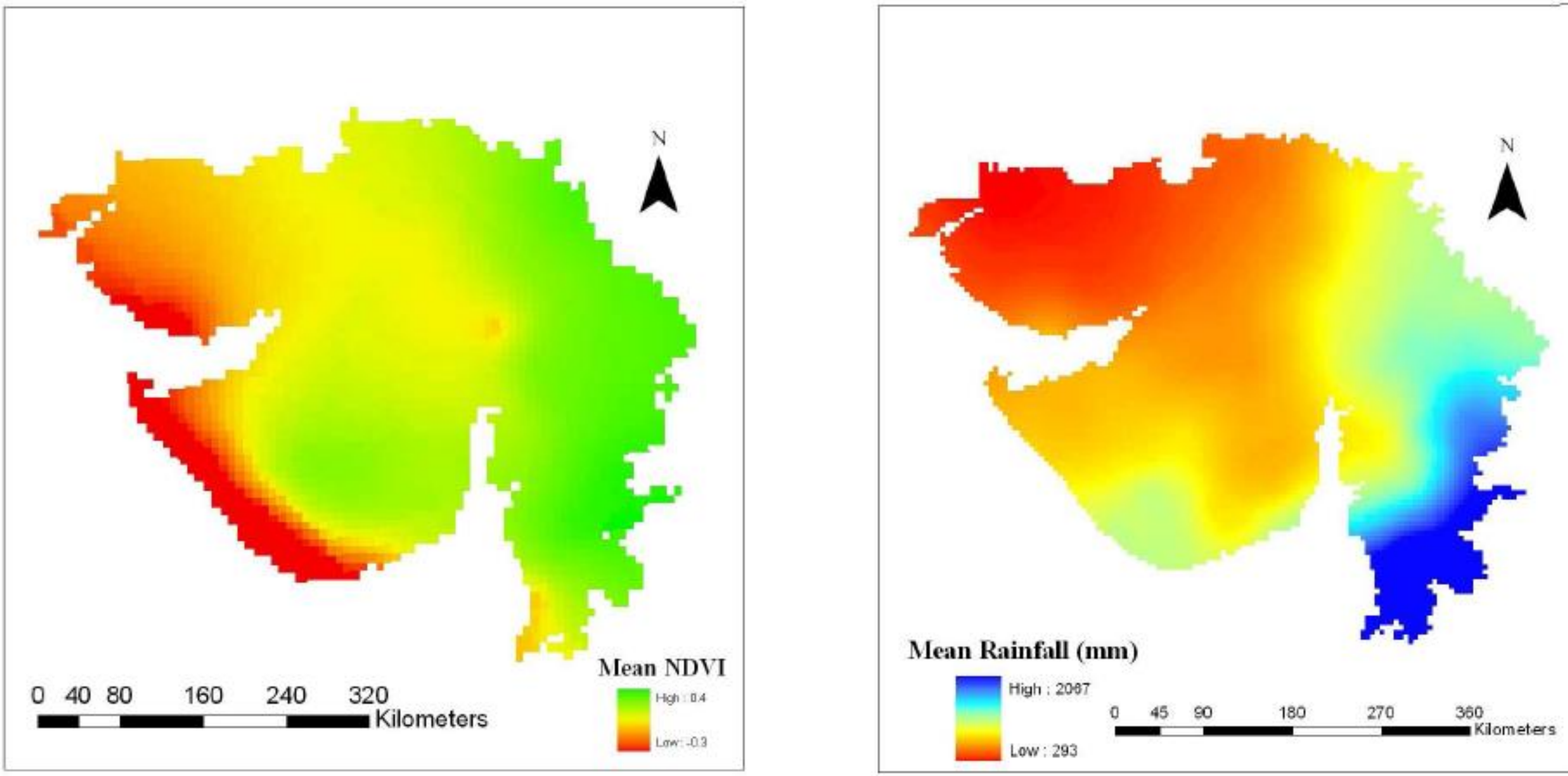


Figure 5-2 Average rainfall and Average NDVI (1981-2000)

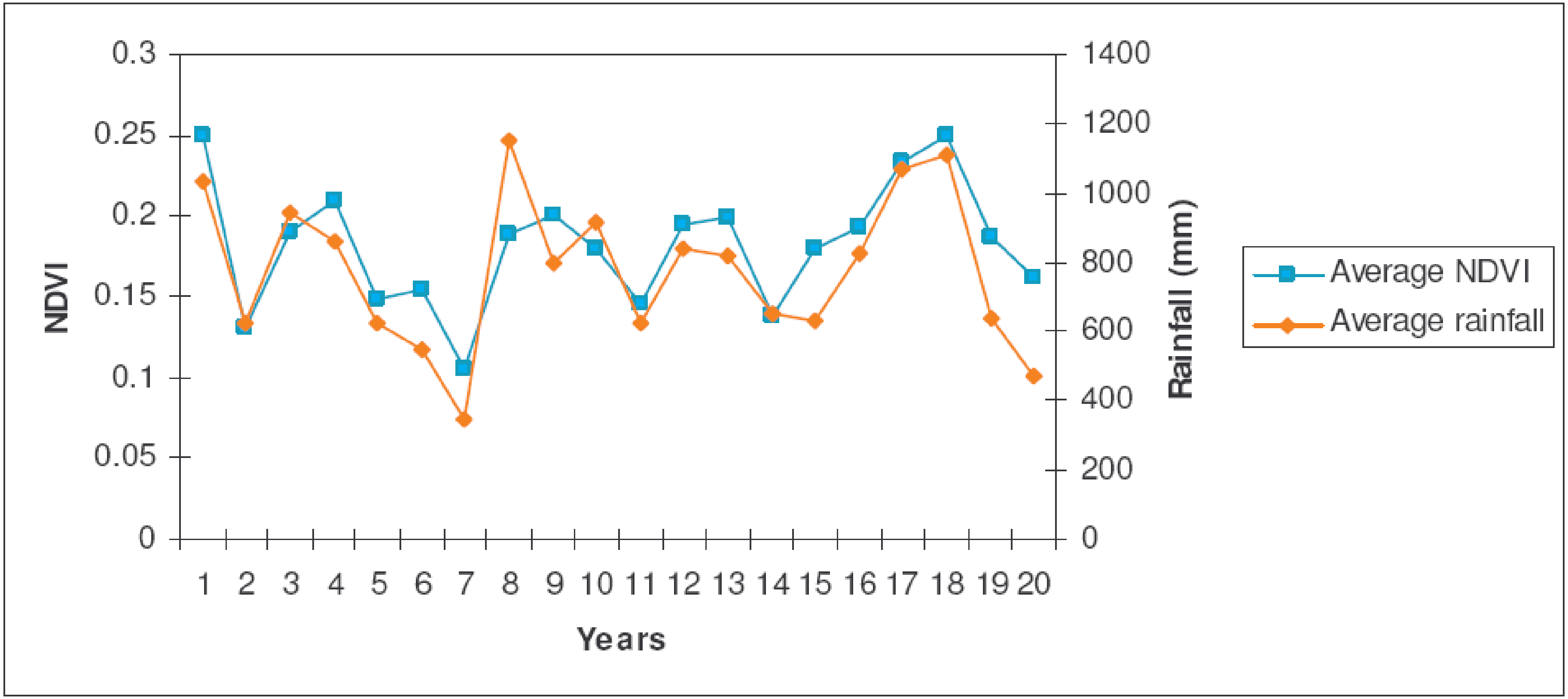
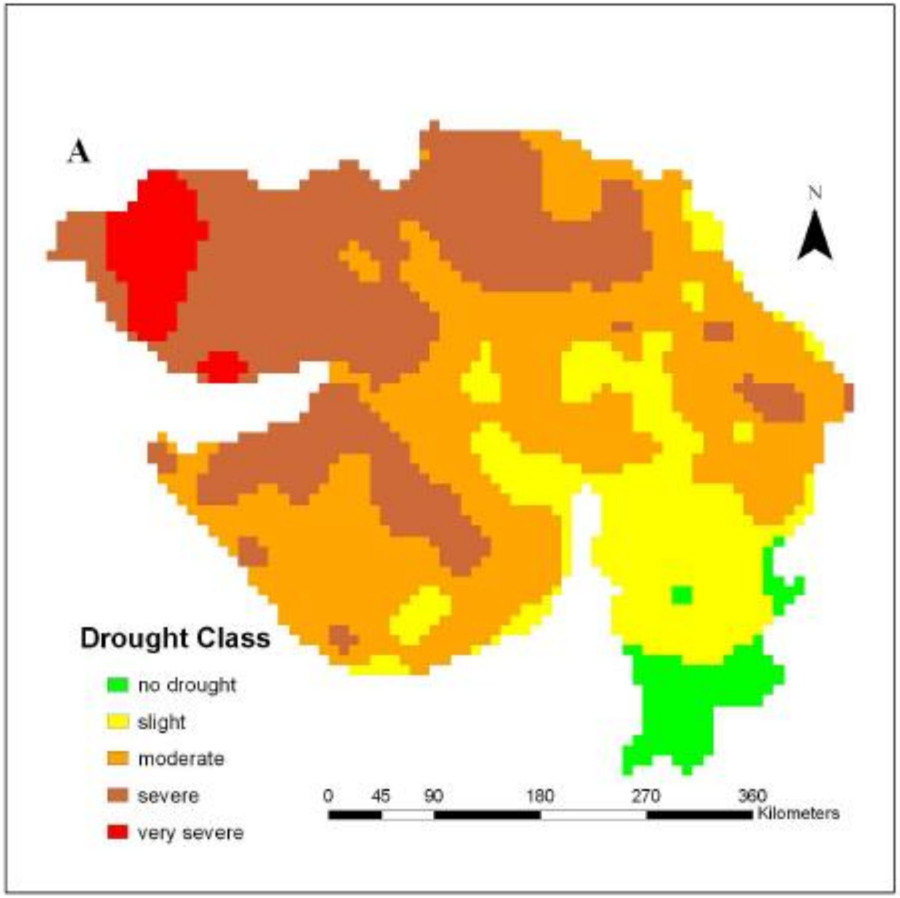
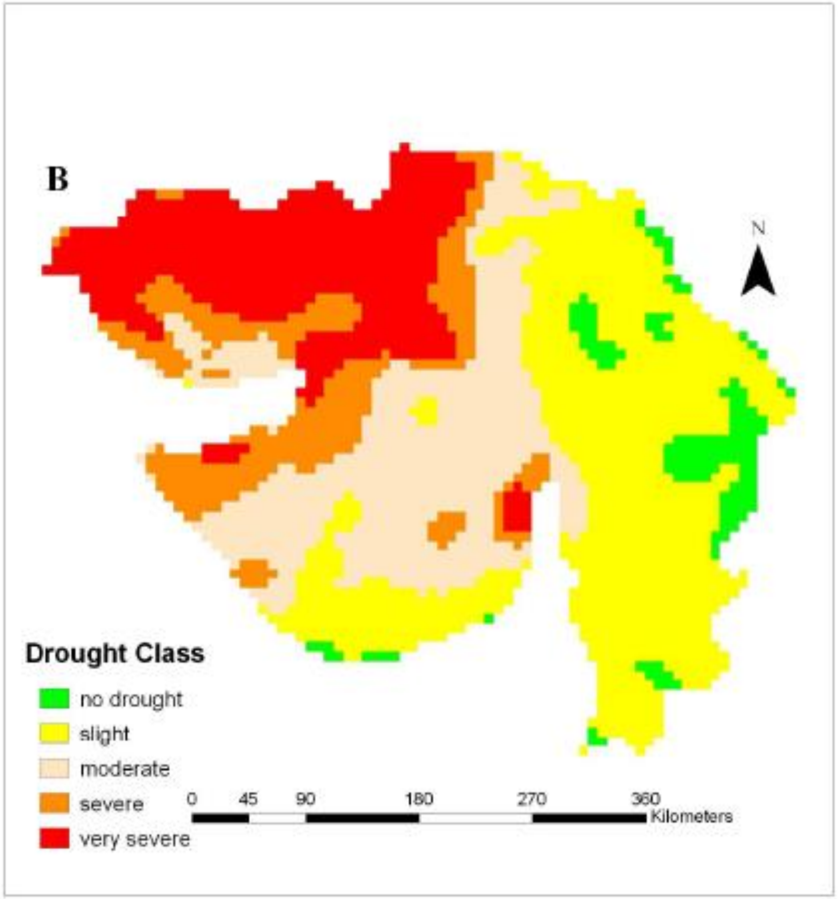


Figure 5-3 Temporal trends of NDVI and Rainfall (1981-2000)





(A) Meteorological Drought Risk and (B) Agriculture Drought Risk

Figure 5-18 Meteorological & Agriculture drought risk

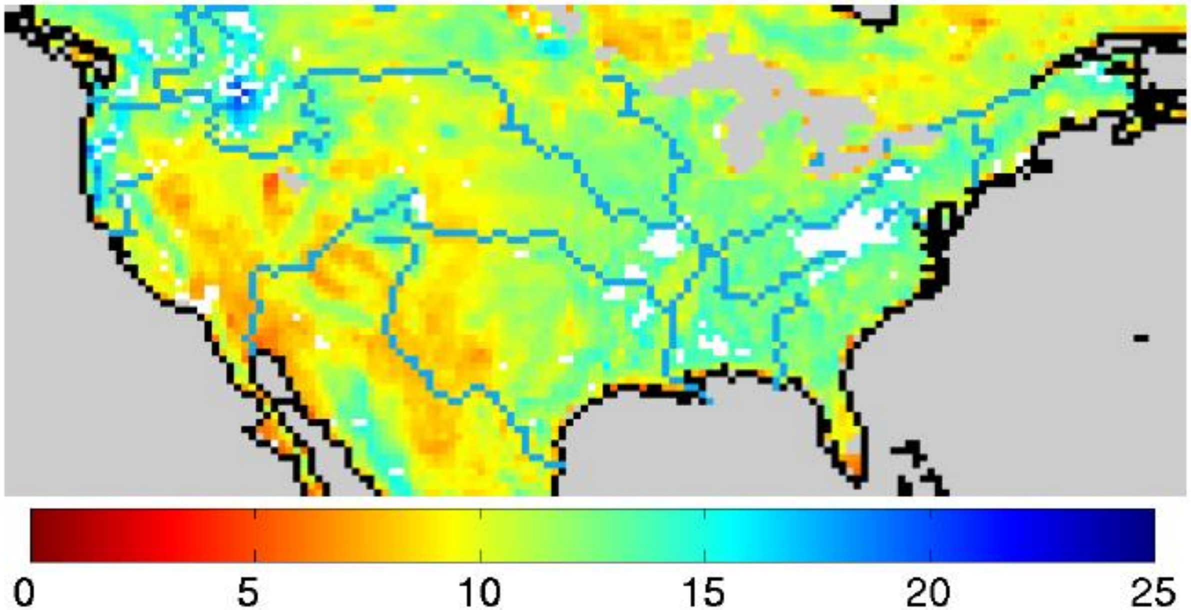


Figure 1. *AMSR-E monthly averaged soil moisture (volumetric %) for August 2002 showing dry conditions over the western U.S.*

Advanced Microwave Scanning Radiometer - Earth Observing System (AMSR-E)

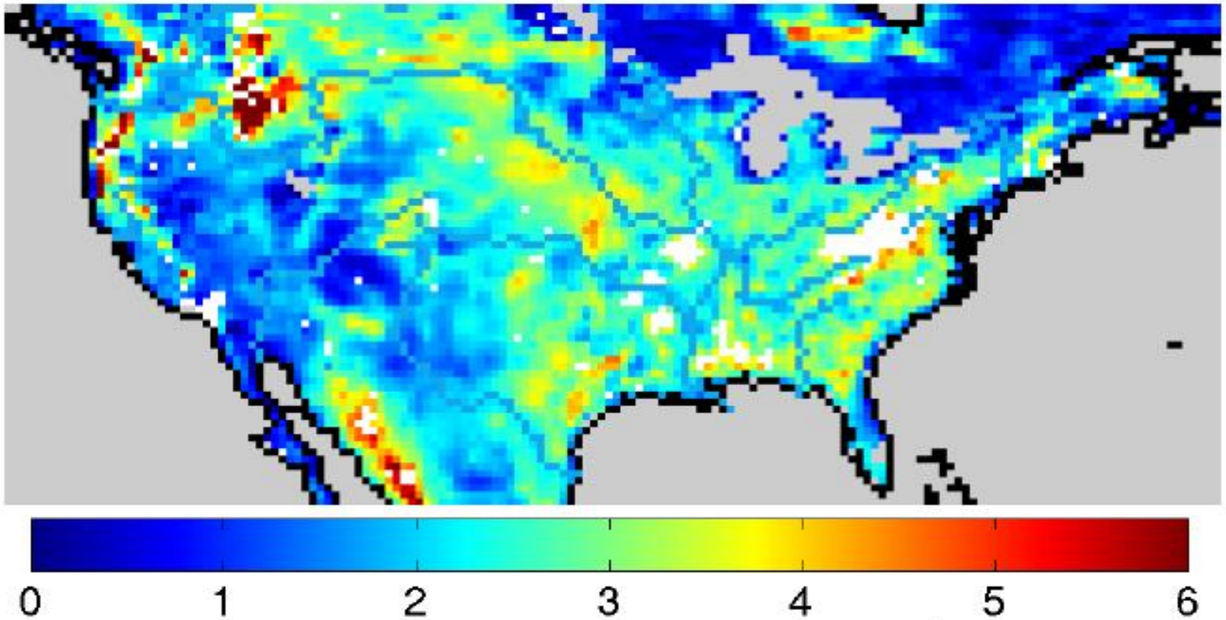
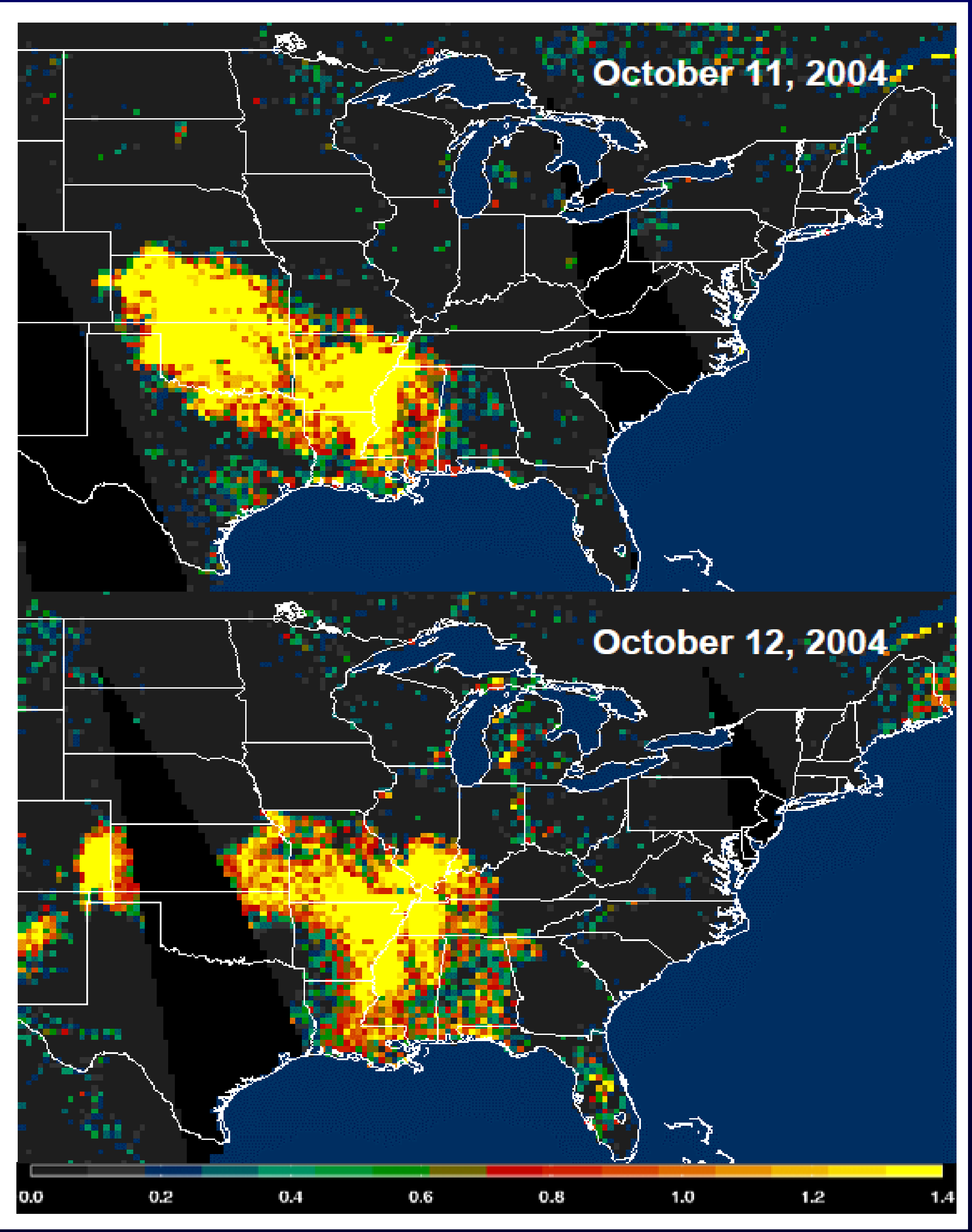


Figure 2. *AMSR-E monthly averaged vegetation water content (kg·m^{-2}) for August 2002 showing moist vegetation over the eastern U.S.*



QSCAT daily maps of surface water increase due to precipitation

the SeaWinds scatterometer aboard the QuikSCAT satellite (QSCAT).

Global scenario on Remote Sensing use for Drought

The normalised difference vegetation index (NDVI) and temperature condition index (TCI) derived from the satellite data are accepted world-wide for regional monitoring.

The ongoing program on Africa Real-Time Environmental Monitoring using Imaging Satellites (ARTEMIS) is operational at FAO and uses METEOSAT rainfall estimates and AVHRR NDVI values for Africa.

The USDA/NOAA Joint Agricultural Weather Facility (JAWF) uses Global OLR anomaly maps, rainfall map, vegetation and temperature condition maps from GOES, METEOSAT, GMS and NOAA satellites.

Canada issues weekly crop condition reports based on NOAA AVHRR based NDVI along with agro meteorological statistics

National Remote Sensing Agency, Department of Space issues biweekly drought bulletin and monthly reports at smaller administrative units for India under National Agricultural Drought Assessment and Monitoring System (NADAMS) which uses NOAA AVHRR and IRS WiFS based NDVI with ground based weather reports.

SOIL EROSION & RESERVOIR SILTATION

Erosion is the process of detachment and transport of soil particles by erosive agents (Ellison, 1944)

Erosion is a natural geologic process

SOIL EROSION: A process of detachment and transportation of soil materials by erosion agents. e.g. water – rainfall and runoff.

RESERVOIR SILTATION: Deposition of transported sand, silt & clay materials in the reservoirs due to reduction in velocity of flowing water.

SOIL ERODABILITY: The natural susceptibility of a soil to erosion i.e., both detachment and transport.

SEDIMENT YIELD: The total sediment outflow from a watershed or drainage basin measurable at a point of reference and in a specified period of time.

REMOTE SENSING: Identification of soil erosion areas using satellite imageries makes the problems solvable very easily and possible to arrest the silt in the catchment itself so as to avoid siltation of reservoirs in downstream sides and protect the soil in the catchment area.

GEOINFORMATICS (GIS): Identification of controlling factors of soil erosion using recently emerging GIS technology reduces the time and cost ratio and enable to adopt suitable remedial measures to control soil erosion in the catchment itself.

IMPACTS OF SOIL EROSION AND RESERVOIR SILTATION

- ➔ Excessive sediment accumulation reduces reservoir storage capacity and more frequent sediment removal is required.
- ➔ Erosion severely diminishes the ability of the soil to support plant growth; and the sand advance to the fertile lands. Thus, the loss in agricultural productivity.
- ➔ Damages the engineering structures such as abrasion in hydel dams and canals.
- ➔ Suspended nutrients trigger algal blooms that reduce water clarity, deplete oxygen, lead to fish kills and create odors.
- ➔ Erosion of stream banks and adjacent areas destroys stream side vegetation
- ➔ Excessive deposition of sediments in streams, blankets the bottom fauna, ‘paves’ stream bottoms and destroys fish pawning areas.
- ➔ Turbidity from sediment reduces in – stream photosynthesis which leads to reduced food supply and habitat.

Soil erosion is broadly classified into two groups, one is geologic and the other one is accelerated. The normal geologic soil erosion is compensated by the formation of new soil cover by weathering process. While the anthropogenic activity intervene these normal processes, then it changes as accelerated soil erosion.

The process of soil erosion is controlled by various factors such as,

- Rainfall
- Slope of the land
- Forest cover removal
- Nature of soil i.e. texture, structure and organic matter
- Water table
- Barren surface
- Continuous dry weather
- Wind velocity

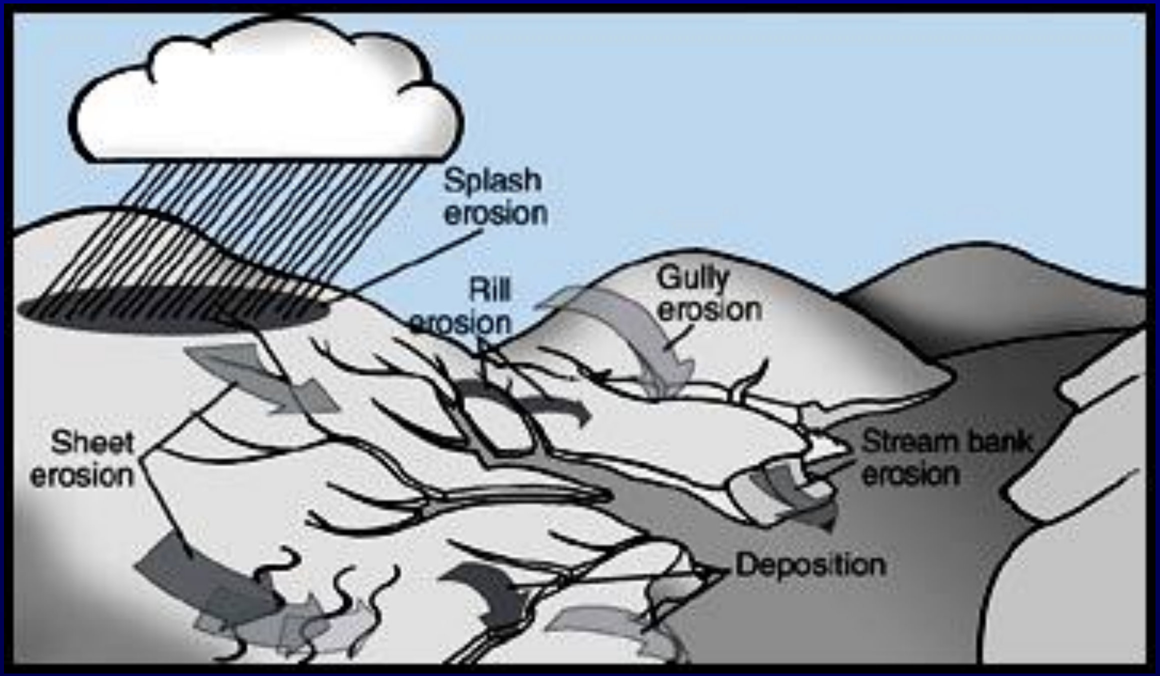
TYPES OF SOIL EROSION

1. SOIL EROSION BY WATER
2. SOIL EROSION BY WIND
3. SOIL EROSION BY GLACIER

Different types of Soil erosion

Types of Soil erosion	Erosion by Water	Rain splash erosion
		Sheet wash erosion
		Rill erosion
		Gulley erosion
		Shore erosion
		Slip erosion
		Stream-bank erosion
	Erosion by Wind	Saltation
		Suspension
		Surface creep
	Erosion by Ice	Plucking
		Abrasion
		Freeze thaw / Frost shattering

TYPES OF SOIL EROSION



Splash erosion

Sheet erosion

Rill erosion

Inter rill erosion

Gully erosion

Channel erosion and

Rain splash erosion: Falling raindrops splash soil. Raindrops fall at a speed of about 20 miles per hour. The raindrop splash beats the bare soil into flowing mud. A single raindrop may splash-wet soil as much as two feet high give feet away.

Sheet erosion: Soil is removed uniformly in thin layer from the entire surface area. Movement of soil by splash erosion is the primary cause of sheet erosion.

Rill erosion: When, run-off water laden with soil flowing along the slopes forming small finger-like channels, rill erosion is formed. Rill erosion is an intermediary stage between sheet erosion and gulley erosion.

Gulley erosion: As the volume of concentrated run-off increases and attains more velocity on slopes, it enlarges the rill into gullies. Gullies often starts along bullock car tracks or burrows of animals. At an advanced stage, gullies result into ravines, which are sometimes 50 to 100 feet deep.

Slip erosion: Landslides cause slope erosion, big masses of soil and rock body slip down damaging the field. The effects of slip erosion are site specific.

Stream-bank erosion: Streams and rivers change their course by cutting one bank and depositing silt loads on the others. During flash floods, the damage is very much accelerated.

Shore erosion: Seashore erosion commonly known as coastal erosion is caused by the striking action of the waves.

Saltation: In saltation, soil particles of medium size (0.10-0.15 mm diameter) are carried by wind in a series of short bounces. The direct pressure of the wind on soil particles causes these bounces.

Surface creeps: Saltation also encourages soil creep (rolling or sliding) along the surface of the large particles (0.5-1.0 mm diameter). The bouncing particles carried by saltation strike the large aggregates and speed up their movement along the surface.

Suspension: When the particles of soil are very small (less than 0.1 mm) they are carried over long distances. Finer suspended particles are moved parallel to the ground surface and upward.

The problems of the soil erosion vary from place to place in our country. For example in northern states, particularly in Assam, shifting cultivation (called ‘Jhum’ cultivation, and ‘chaparies’), is responsible for soil erosion.

Whereas in Rajasthan, wind erosion is the dominant phenomenon. In Punjab, soil erosion is caused by ‘chos’ – sand torrent in the Siwalik foothills.

In the state of Maharastra, the problem of soil erosion is in the form of moisture loss.

In southern states, particularly Tamil Nadu and Kerala, the cause for soil erosion is misuse of land in the form of removal of natural forest cover to plantation purposes such as tea, coffee, cinchona and eucalyptus. In Andhra Pradesh and Karnataka, sheet erosion is common in the low rainfall areas.

CONTROLLING FACTORS OF SOIL EROSION

Erosive potential of an area depends on,

- **Climate – rain drop size, intensity, distribution, fall velocities, total mass of impact and temperate.**
- **Characteristics of soil – texture, structure, permeability, compactness and infiltration capacity**
- **Vegetal cover – types of vegetation, density, root systems**
- **Topography – slope, slope length, slope configuration and surfacial features**
- **Human activities – landuse, construction practices, agricultural operations, landuse conversion to rocky wastes, deforestation, industrial waste disposals, mining and mine waste gushing.**

Soil Erosion Controlled by Geoscientific parameters such as

- Geology
- Structure of the area
- Geomorphology
- Subsurface geology
- Drainage Density
- Water level / table
- Slope
- Land use / Land cover
- Climate

PRINCIPLES OF SOIL EROSION AND SEDIMENT CONTROL

- Retain existing vegetation wherever feasible
- Vegetate in denuded areas
- Divert runoff away from denuded areas
- Minimise length and steepness of slopes
- Keep runoff velocities low
- Prepare drainage ways and outlets to handle concentrated or increased runoff
- Trap sediment on site
- Inspect and maintain control measures.

MEASUREMENT OF SOIL EROSION

The Universal Soil Loss Equation (USLE) – designed by two soil scientists namely, Wischmeier and Smith during the year 1978 is to predict the soil loss in the field.

$$A = R * K * LS * C * P$$

The Universal Soil Loss Equation (USLE) predicts the long term average annual rate of erosion on a field slope based on rainfall pattern, soil type, topography, crop system and management practices

A = Soil loss in tons/ha/year

R = Rainfall and runoff factor

K = soil erodability factor

LS = Slope length-gradient factor

C = vegetative cover factor

P = conservation practice factor

R= rainfall factor. The value of this factor is determined by the amount and intensity of rainfall determined by location in the country.

K = soil erosivity factor. The value of this factor depends upon soil texture (mineral composition) and structure (the proportion of air, organic matter and water that gives a soil its structure.)

LS = Length of slope factor. This factor accounts for the effects of the grade of a field and the shape of its slopes. It is important to realize that it does not take a steep slope to move a lot of soil. A gentle but long slope can results in high levels of erosion.

C = Cultural practices factor. This factor accounts for the impact of crop rotations (pasture, legumes, corn, etc.) that will provide varying degrees of soil cover. Also, this factor includes conservation tillage practices and other cultural practices can reduce or enhance substantially soil loss.

P= Supporting Practices factor. This factor accounts for management pratices such as construction of terraces or contour strips that keep water at about the same elevation in a field, and thus avoid direct downhill flow.

K Factor Data – Soil erodability factor (Organic Matter Content)

Textural Class	Average	Less than 2 %	More than 2 %
Clay	0.22	0.24	0.21
Clay Loam	0.30	0.33	0.28
Coarse Sandy Loam	0.07	--	0.07
Fine Sand	0.08	0.09	0.06
Fine Sandy Loam	0.18	0.22	0.17
Heavy Clay	0.17	0.19	0.15
Loam	0.30	0.34	0.26
Loamy Fine Sand	0.11	0.15	0.09
Loamy Sand	0.04	0.05	0.04
Loamy Very Fine Sand	0.39	0.44	0.25
Sand	0.02	0.03	0.01
Sandy Clay Loam	0.20	-	0.20
Sandy Loam	0.13	0.14	0.12
Silt Loam	0.38	0.41	0.37
Silty Clay	0.26	0.27	0.26
Silty Clay Loam	0.32	0.35	0.30
Very Fine Sand	0.43	0.46	0.37
Very Fine Sandy Loam	0.35	0.41	0.33

Table 3A. LS Factor Calculation

Slope Length ft (m)	Slope (%)	LS Factor
	10	1.3800
	8	0.9964
	6	0.6742
	5	0.5362
100 ft (31 m)	4	0.4004
	3	0.2965
	2	0.2008
	1	0.1290
	0	0.0693

Table 4A. Crop Type Factor

Crop Type	Factor
Grain Corn	0.40
Silage Corn, Beans & Canola	0.50
Cereals (Spring & Winter)	0.35
Seasonal Horticultural Crops	0.50
Fruit Trees	0.10
Hay and Pasture	0.02

Soil Loss Tolerance Rates

Soil Erosion Class	Potential Soil Loss (tons/acre/year)
Very Low (tolerable)	<3
Low	3 - 5
Moderate	5 - 10
High	10 - 15
Severe	>15

Table 7. Management Strategies to Reduce Soil Losses

Factor	Management Strategies	Example
R	The R Factor for a field cannot be altered.	--
K	The K Factor for a field cannot be altered.	--
LS	Terraces may be constructed to reduce the slope length resulting in lower soil losses.	Terracing requires additional investment and will cause some inconvenience in farming. Investigate other soil conservation practices first.
C	The selection of crop types and tillage methods that result in the lowest possible C factor will result in less soil erosion.	Consider cropping systems that will provide maximum protection for the soil. Use minimum tillage systems where possible.
P	The selection of a support practice that has the lowest possible factor associated with it will result in lower soil losses.	Use support practices such as cross slope farming that will cause deposition of sediment to occur close to the source.

VEGETATIVE METHODS OF SOIL STABILIZATION

Vegetal cover reduces erosion by,

- Absorbing the impact of raindrops
- Reducing the velocity of runoff
- Reducing runoff volumes by increasing water percolation in to the soil
- Binding soil with roots
- Protecting soil from wind

This method needs

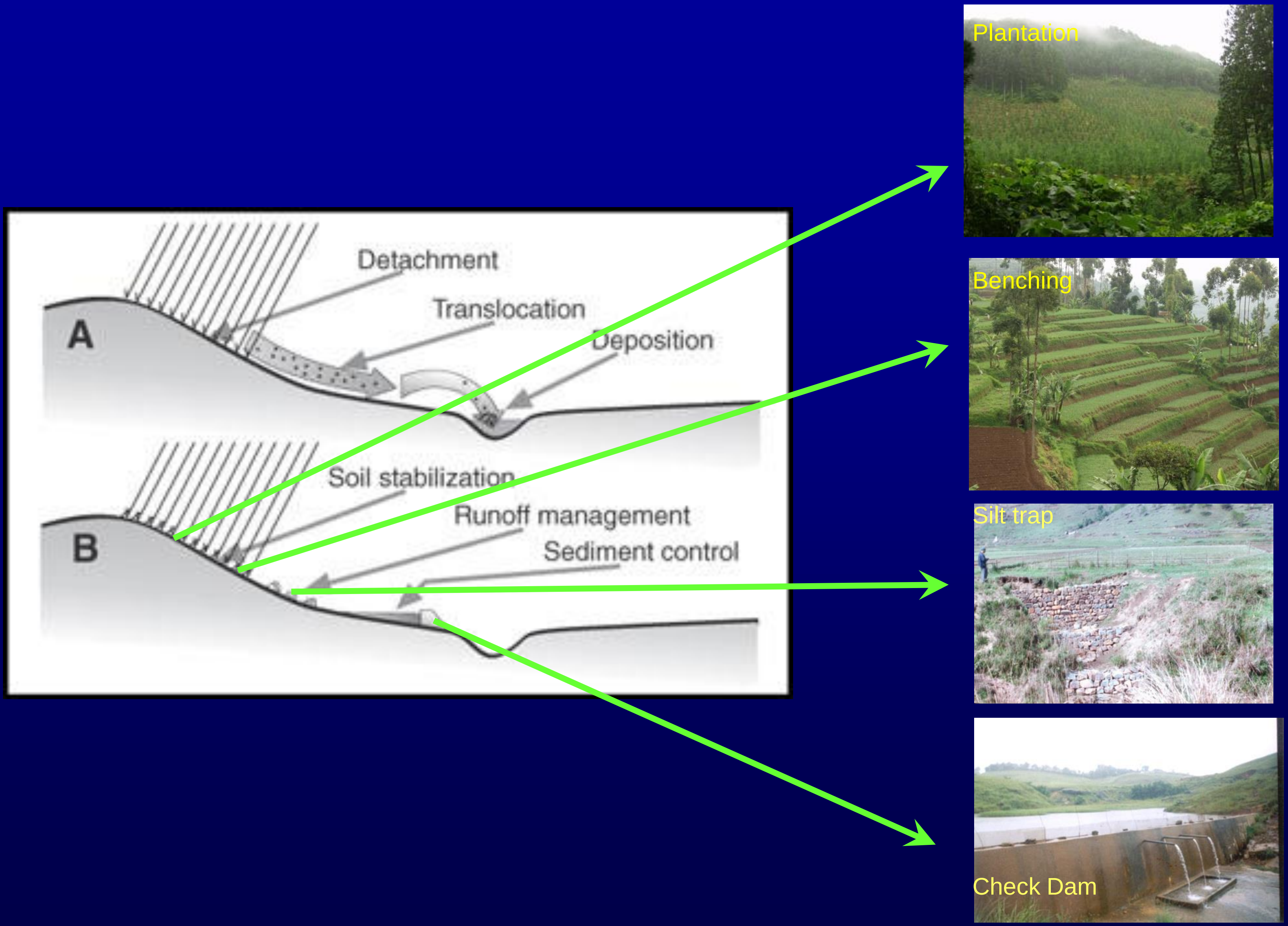
- Careful selection of plants
- Site preparation, seeding
- Fertilizing and
- Mulching

MECHANICAL METHODS OF SOIL EROSION CONTROL

Contouring / Contour cultivation, Contour strip cropping, Contour bunds Terracing, Terrace cultivation

Water conveyance structures

- Grassed water ways
- Check dams
- Dikes and swales
- Pipe slope drains and paved chutes
- Permanent water ways,
- Channel linings
  - Gravel lined swale
  - Rock lined water ways
  - Plastic lined ditches
- Wind breaks
- Changing soil humus levels and tillage practices
- Geotextiles

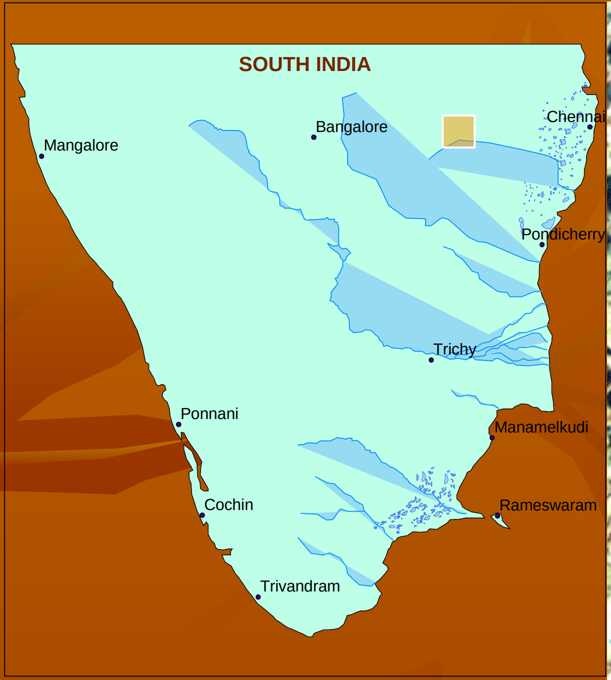

A
Detachment
Translocation
Deposition
B
Soil stabilization
Runoff management
Sediment control
Plantation
Benching
Silt trap
Check Dam

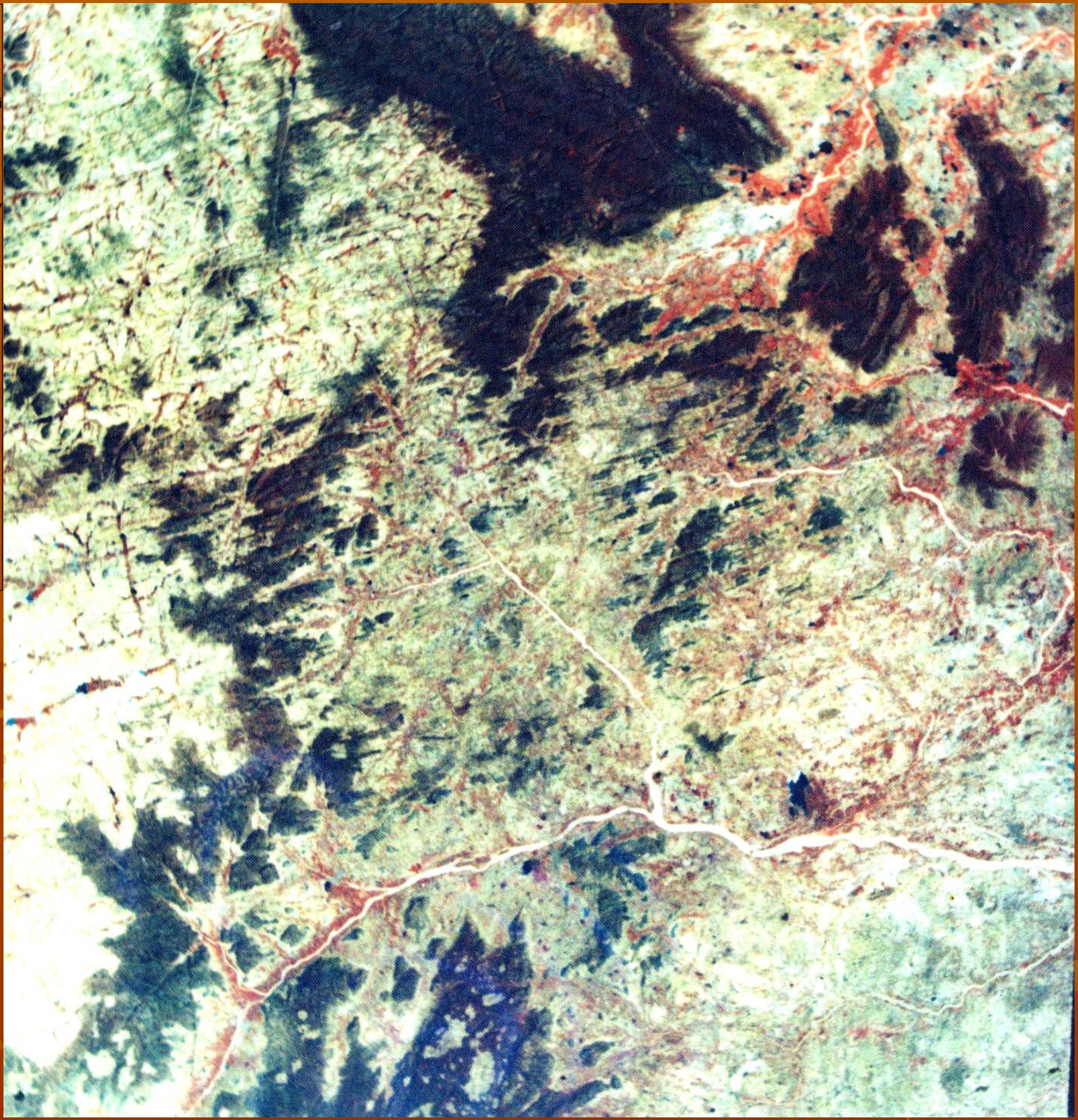
Identification of Soil Erosion Prone Areas,

Soil Erosion Functional Model

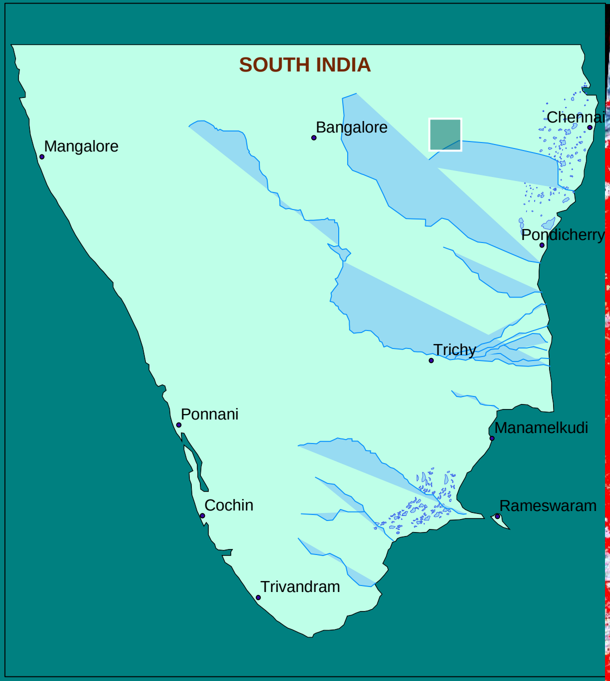
Conservation Measures

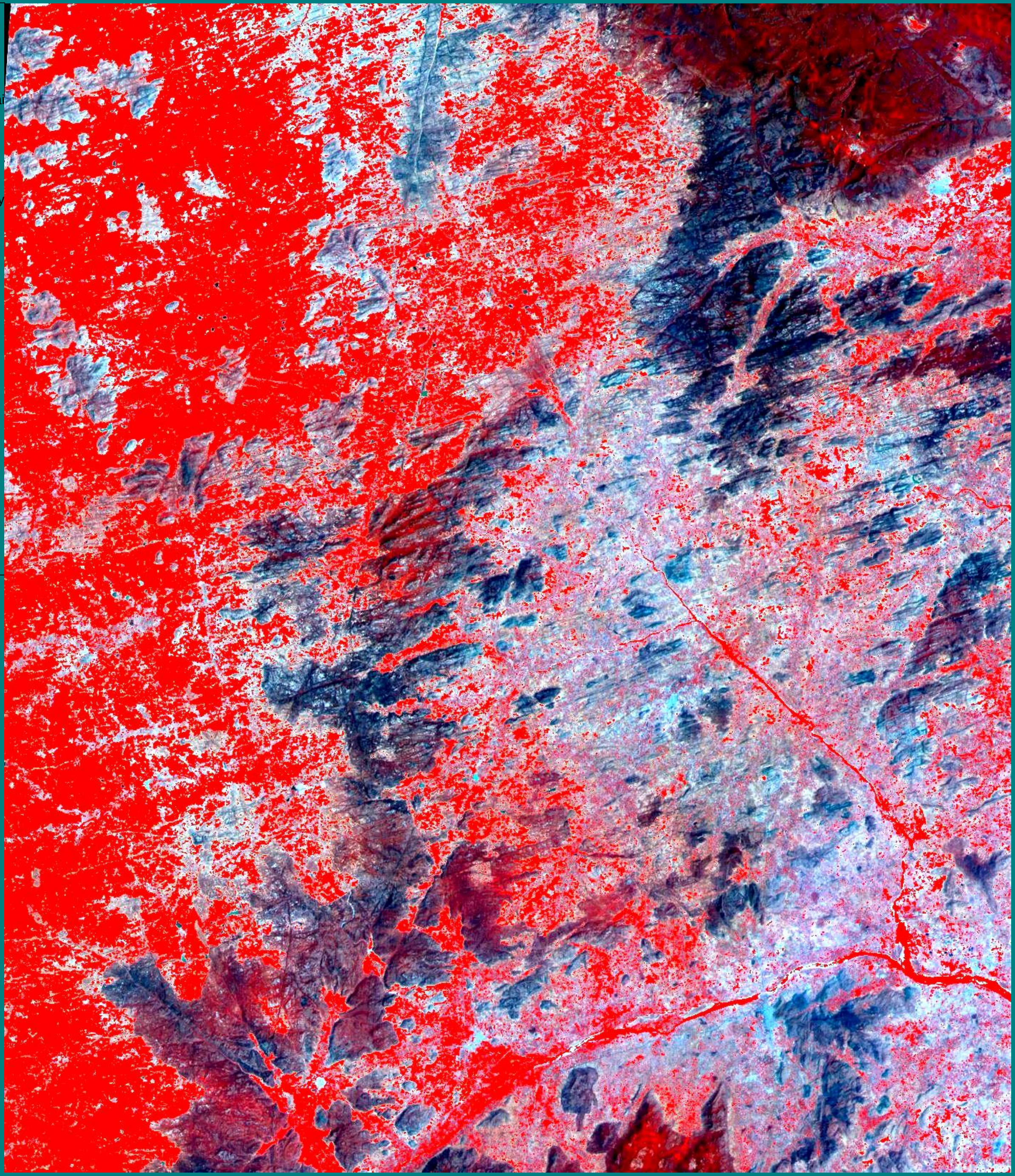
Using Remote Sensing and GIS



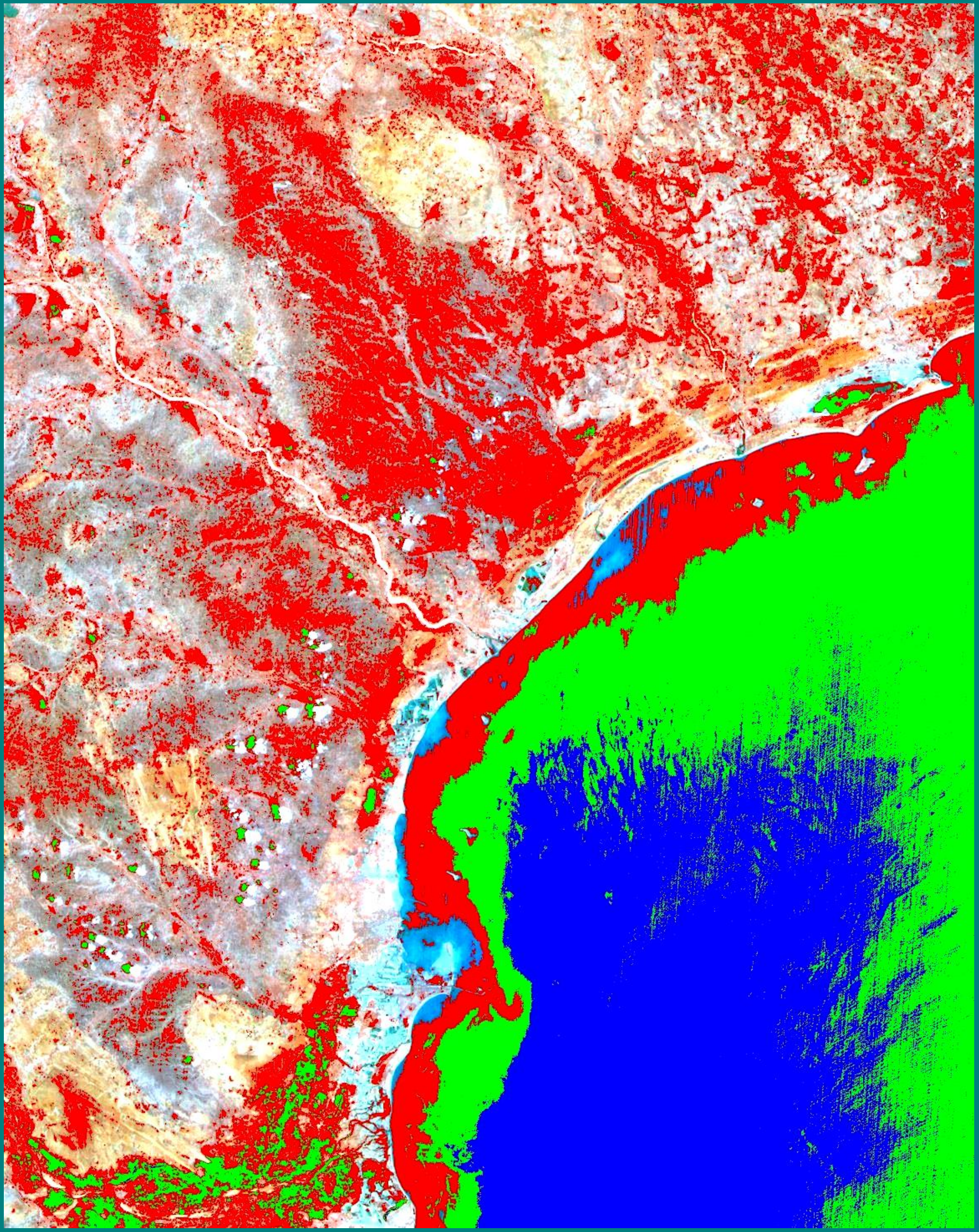


SOIL EROSION IN CHENNAI REGION



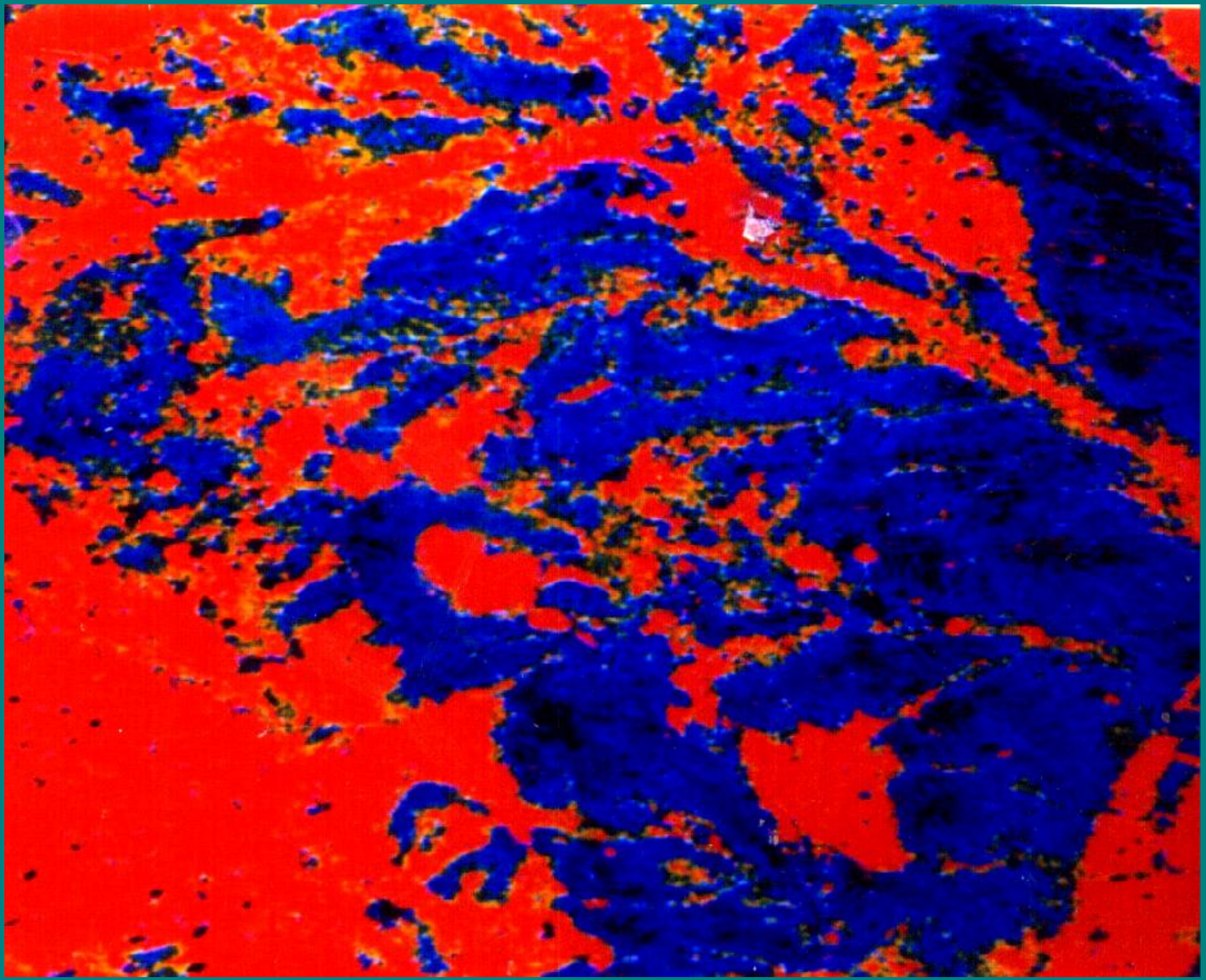


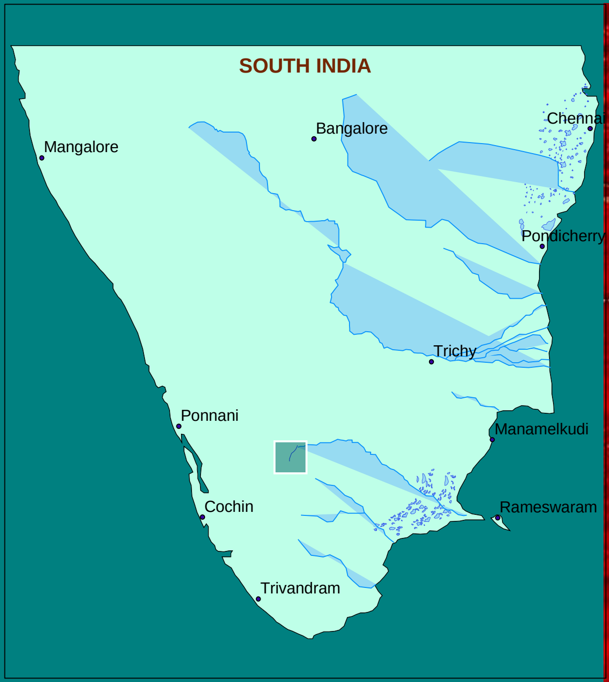
SOIL EROSION IN CHENNAI REGION – PROCESSED IMAGE



SOIL EROSION AND SEDIMENT DUMPING IN VAIPPAR REGION

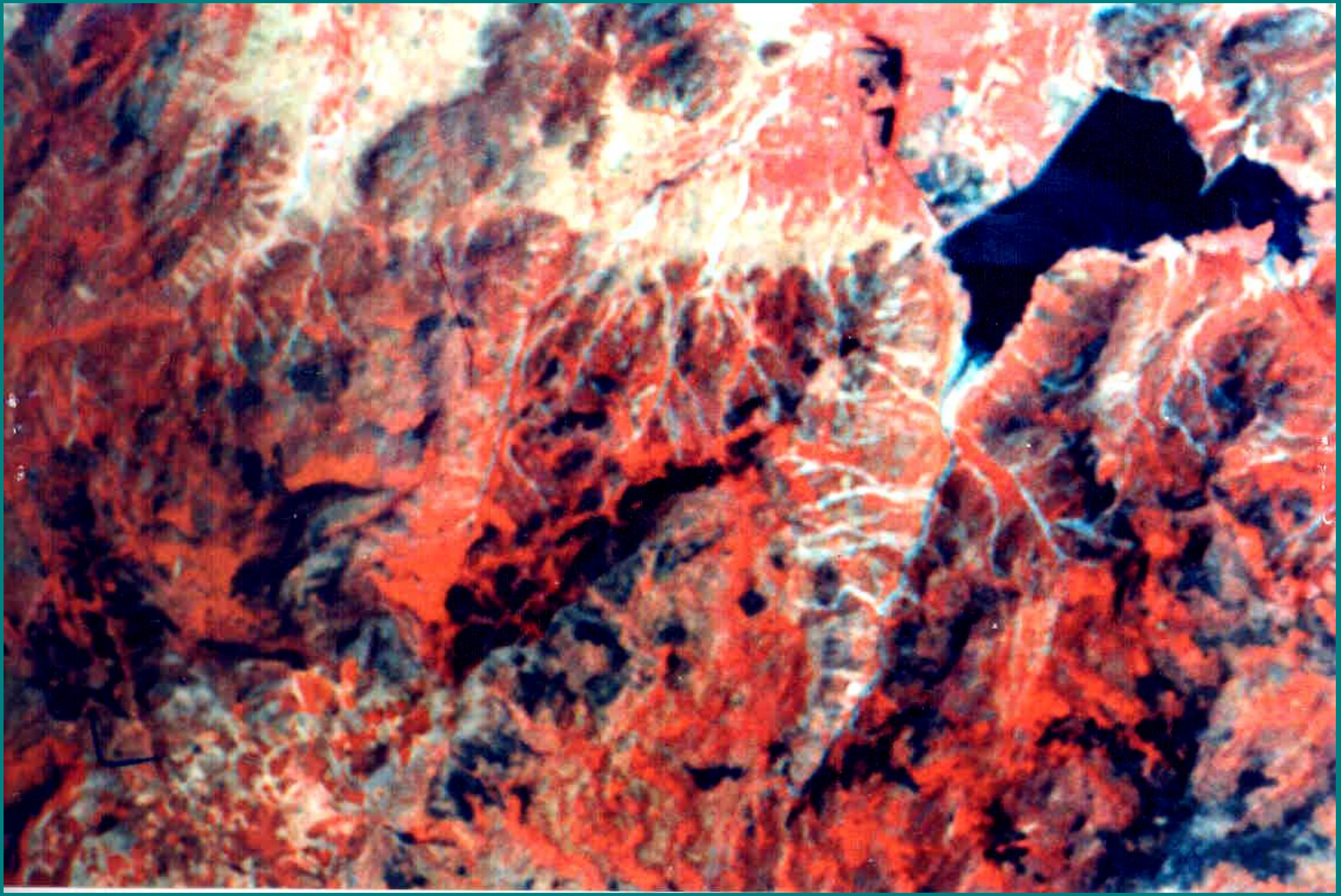
SOIL EROSION IN VAIPPAR REGION



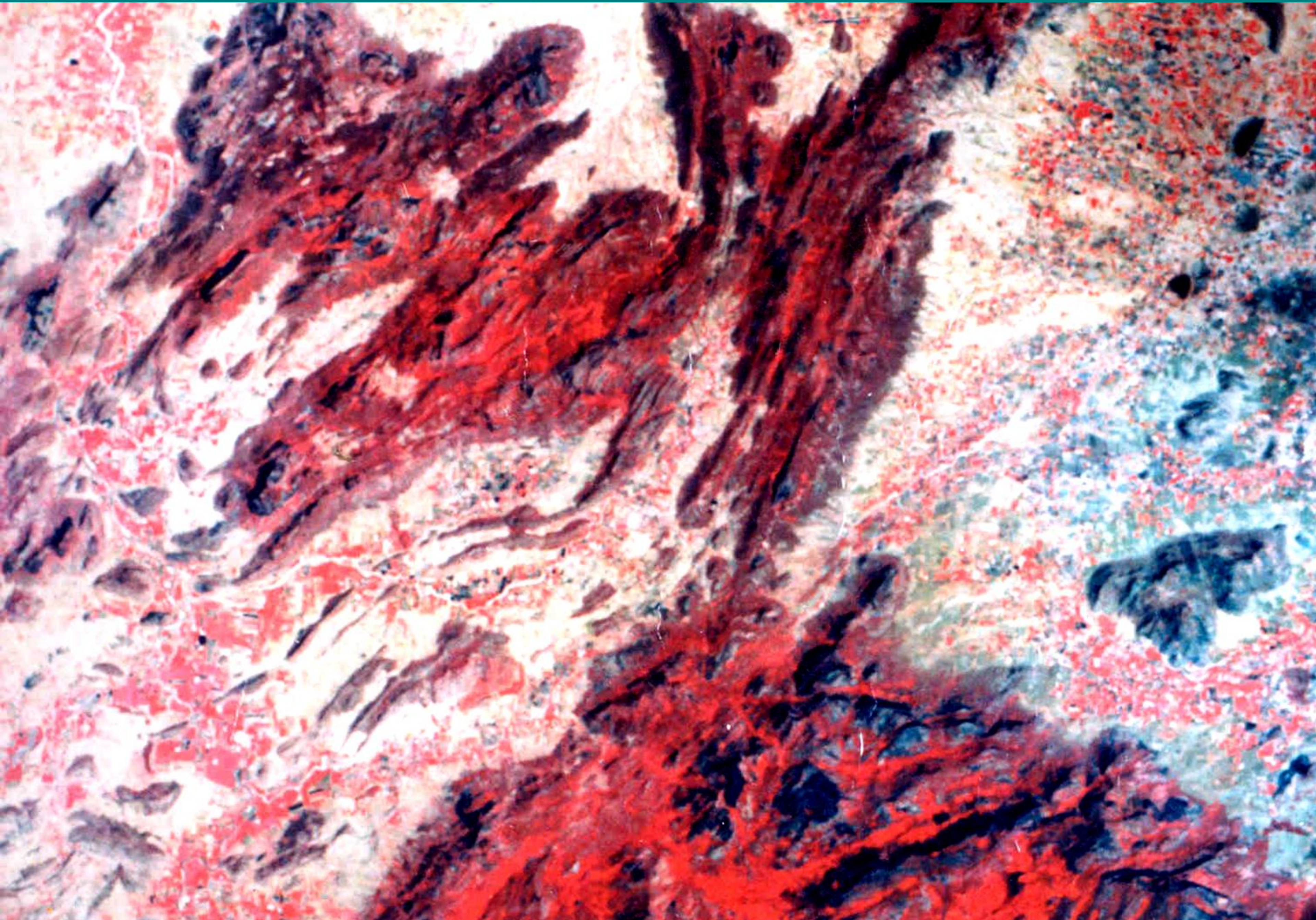


SOIL EROSION IN VAIGAI CATCHMENT

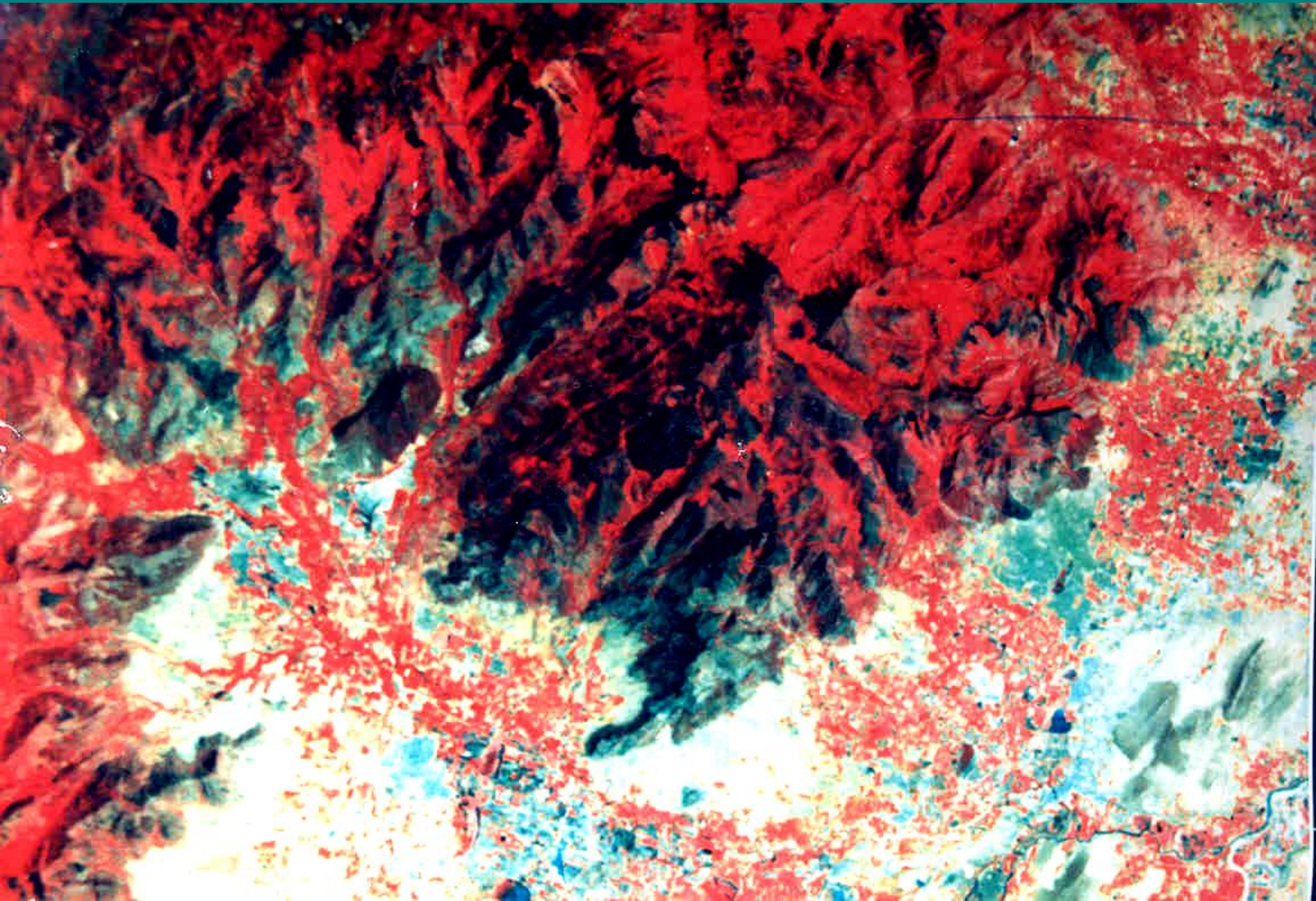
PARTS OF KODAI HILLS – FIRST ORDER DRAINAGES



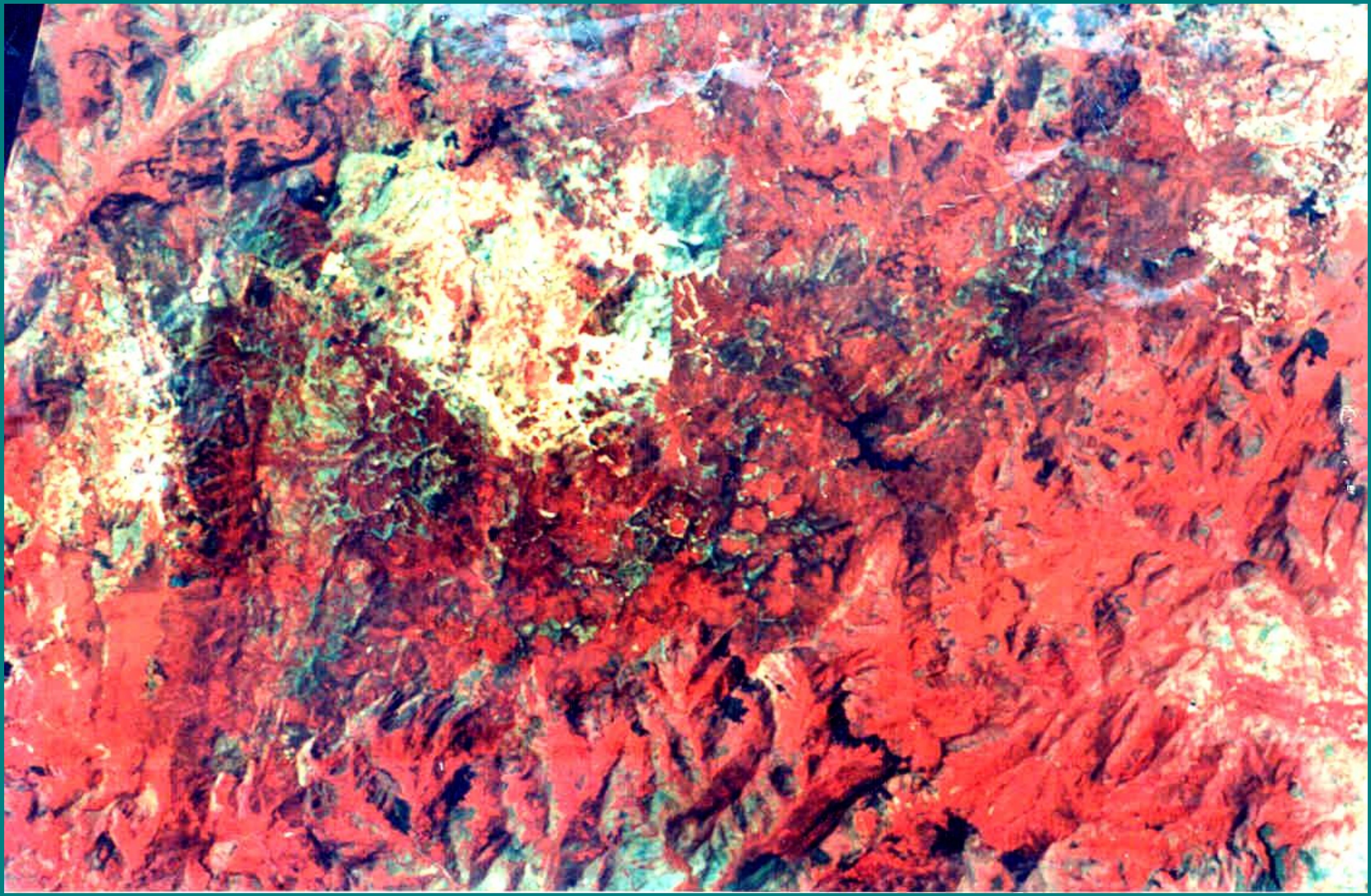
PARTS OF KODAI HILLS – ACTIVE FOOT HILLS



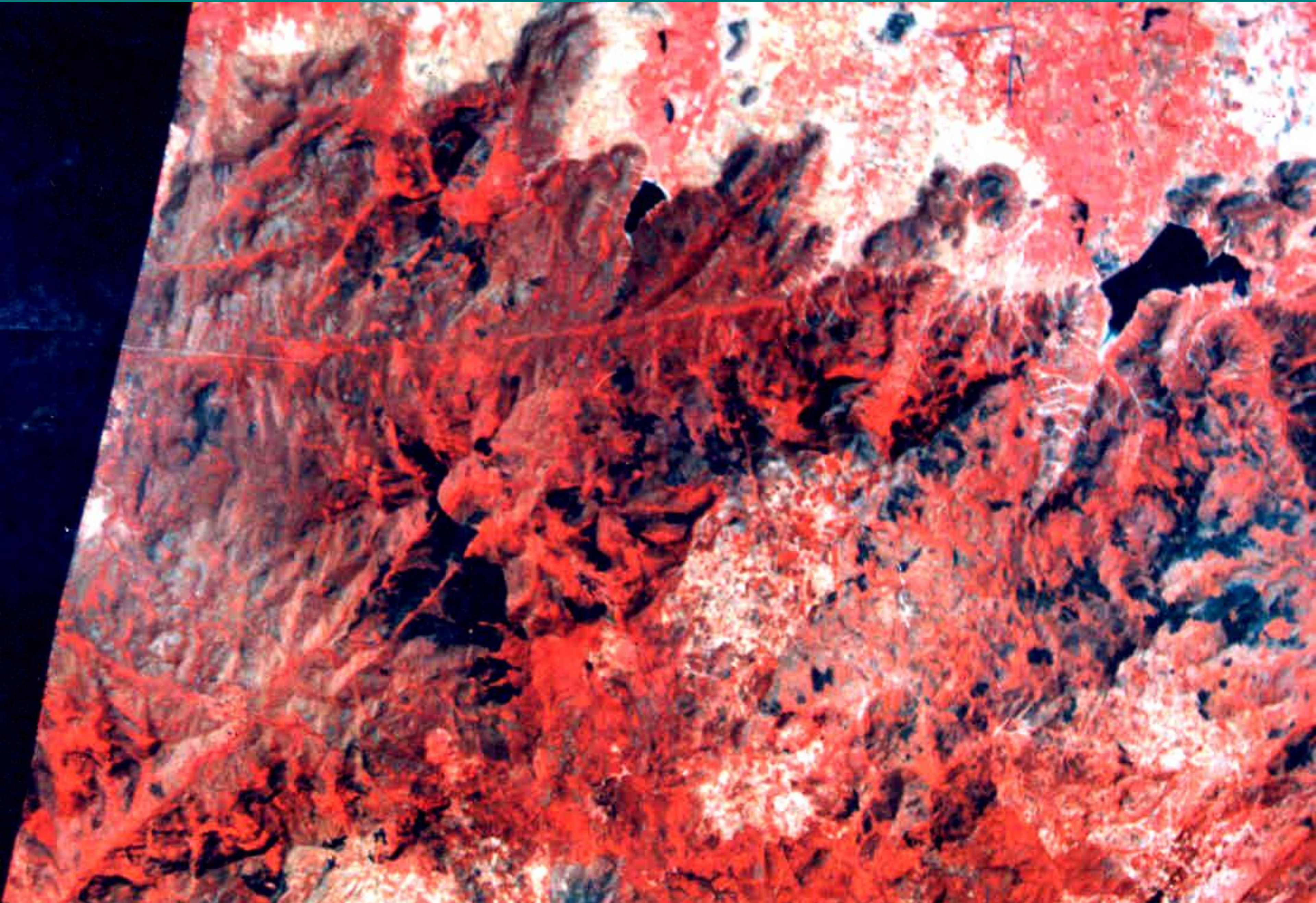
PARTS OF KODAI HILLS – ACTIVE SLOPES



PARTS OF KODAI HILLS – EROSION PRONE LITHOLOGY



PARTS OF KODAI HILLS – EROSION PRONE FRACTURES / LINEAMENTS



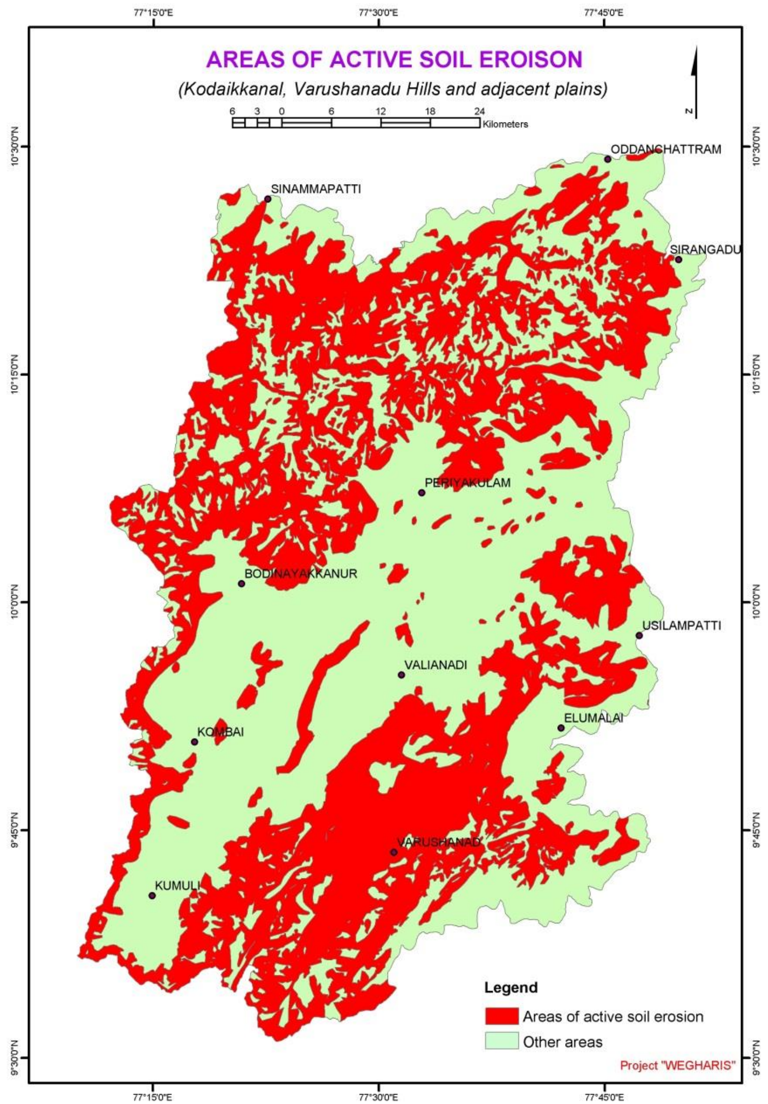

AREAS OF ACTIVE SOIL EROISON
(Kodaikkanal, Varushanadu Hills and adjacent plains)
6 3 0 6 12 18 24 Kilometers
N
77°15'0"E
77°30'0"E
77°45'0"E
10°30'0"N
10°15'0"N
10°0'0"N
9°45'0"N
9°30'0"N
ODDANCHATTRAM
SINAMMAPATTI
SIRANGADU
PERIYAKULAM
BODINAYAKKANUR
USILAMPATTI
VALIANADI
ELUMALAI
KOMBAI
VARUSHANAD
KUMULI
Legend
Areas of active soil erosion
Other areas
Project "WEGHARIS"

Fig. 4.10

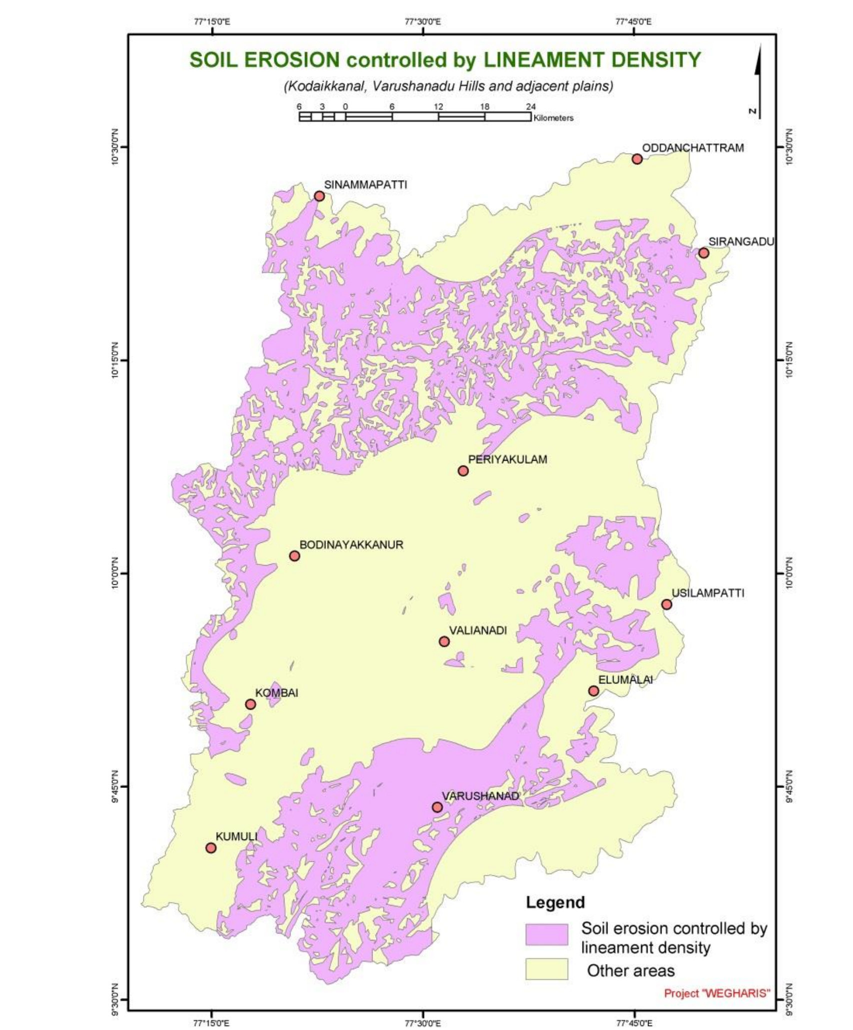

SOIL EROSION controlled by LINEAMENT DENSITY
(Kodaikkanal, Varushanadu Hills and adjacent plains)
Kilometers
ODDANCHATTRAM
SINAMMAPATTI
SIRANGADU
PERIYAKULAM
BODINAYAKKANUR
USILAMPATTI
VALIANADI
ELUMALAI
KOMBAI
VARUSHANAD
KUMULI
Legend
Soil erosion controlled by lineament density
Other areas
Project "WEGHARIS"

Fig. 2.5

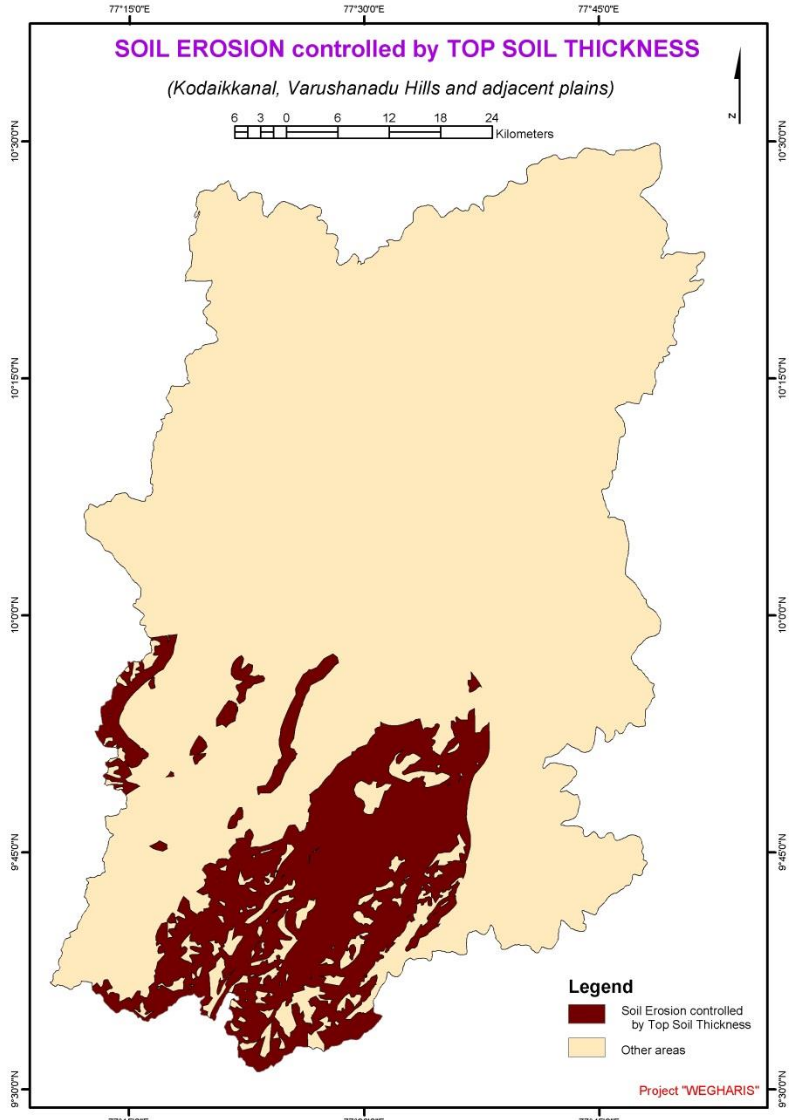

SOIL EROSION controlled by TOP SOIL THICKNESS
(Kodaikkanal, Varushanadu Hills and adjacent plains)
6 3 0 6 12 18 24
Kilometers
N
77°15'0"E
77°30'0"E
77°45'0"E
10°30'0"N
10°15'0"N
10°0'0"N
9°45'0"N
9°30'0"N
Legend
Soil Erosion controlled by Top Soil Thickness
Other areas
Project "WEGHARIS"

Fig. 4.12

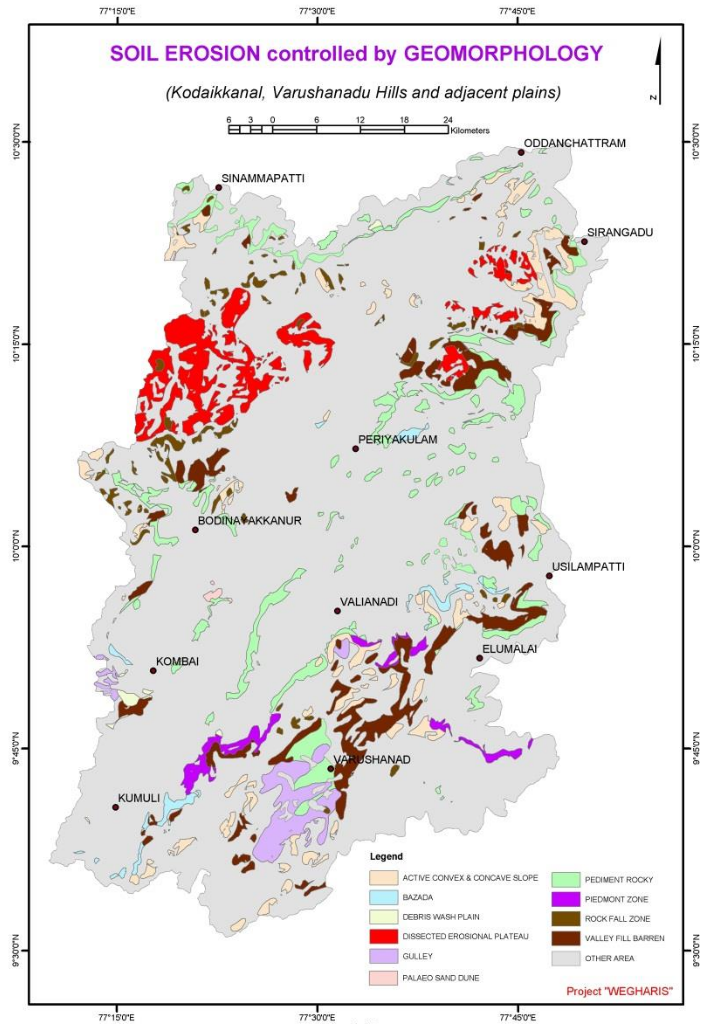
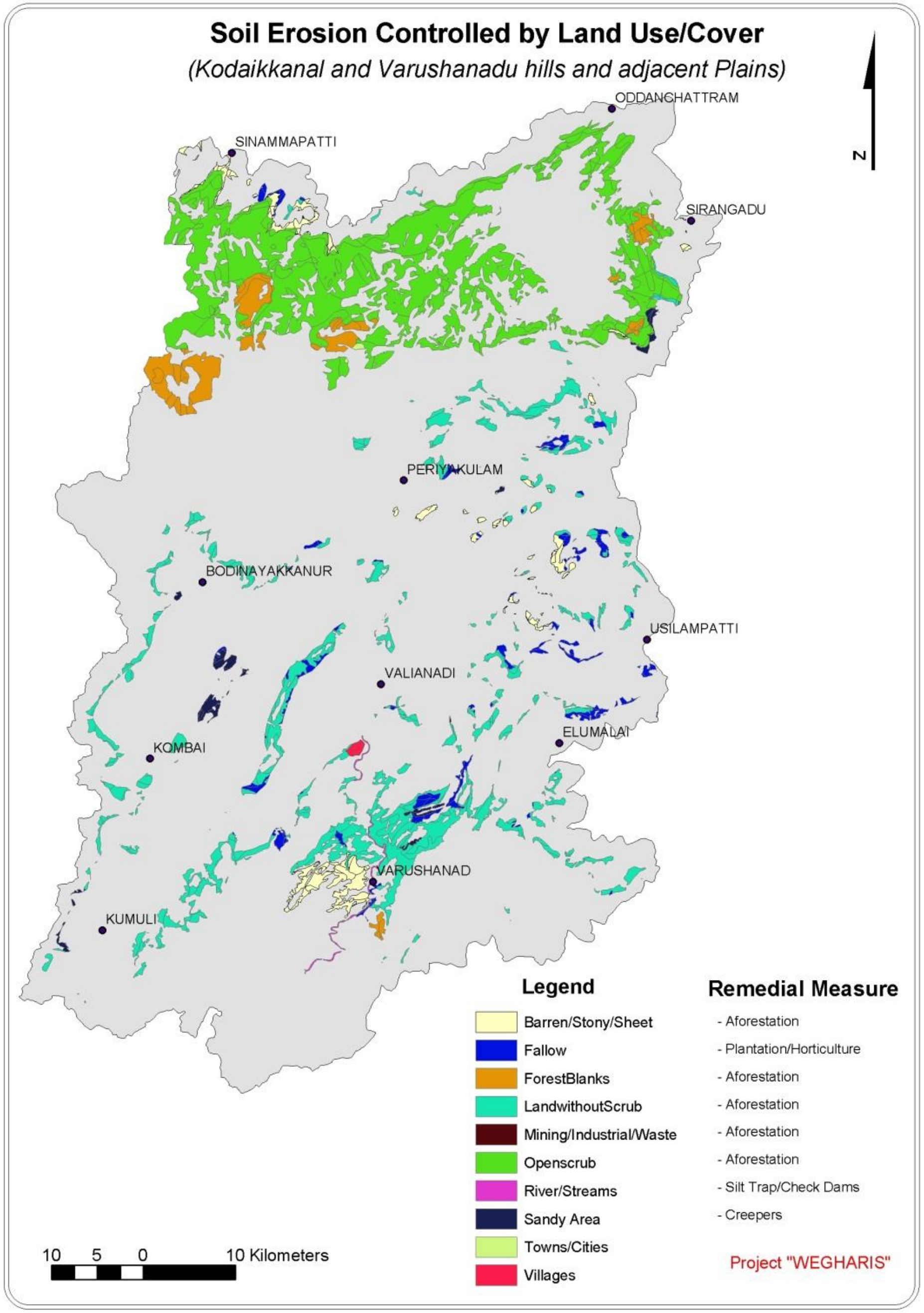
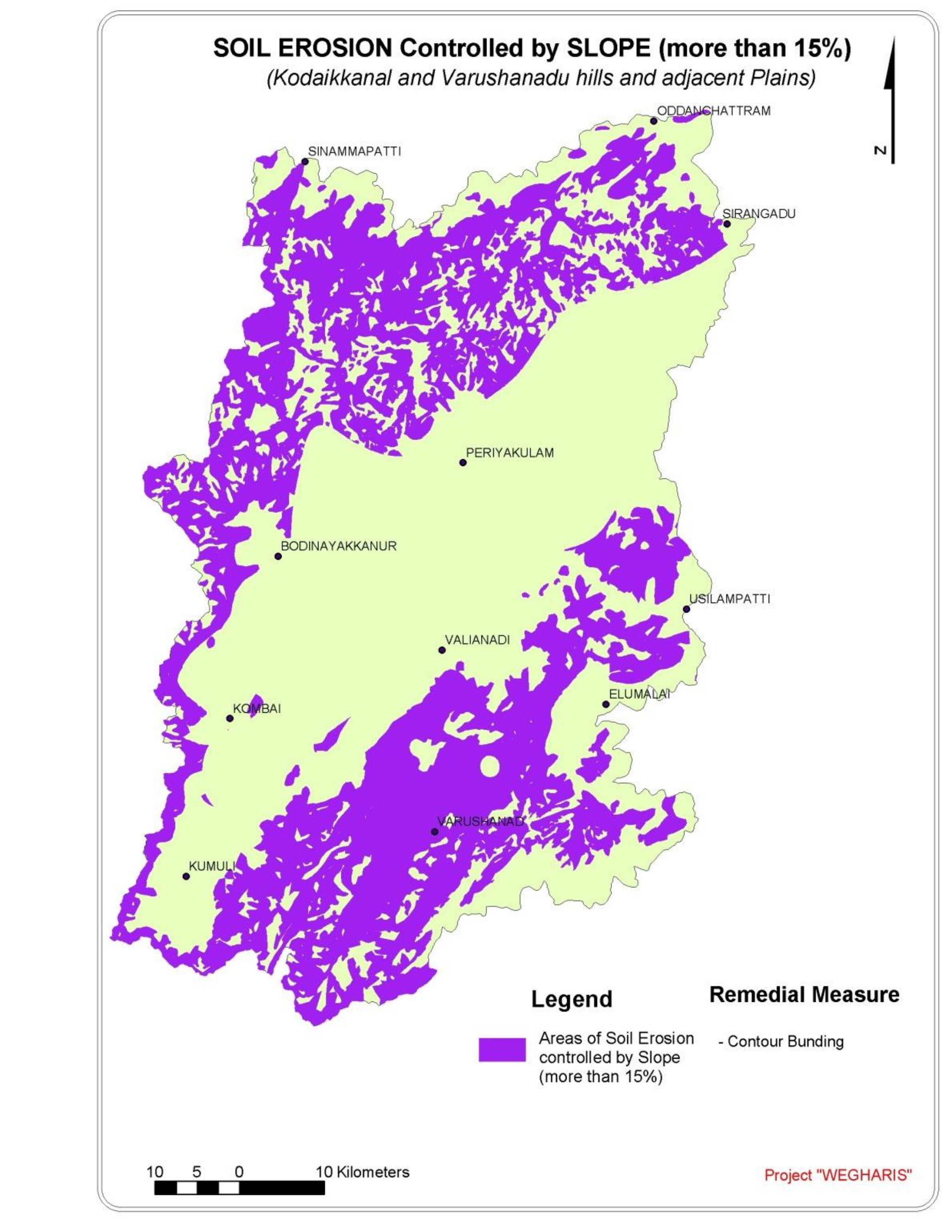

SOIL EROSION controlled by GEOMORPHOLOGY
(Kodaikkanal, Varushanadu Hills and adjacent plains)
77°15'0"E
77°30'0"E
77°45'0"E
10°30'0"N
10°15'0"N
10°0'0"N
9°45'0"N
9°30'0"N
6 3 0 6 12 18 24
Kilometers
N
ODDANCHATTRAM
SINAMMAPATTI
SIRANGADU
PERIYAKULAM
BODINAYAKKANUR
USILAMPATTI
VALIANADI
ELUMALAI
KOMBAI
VARUSHANAD
KUMULI
Legend
ACTIVE CONVEX & CONCAVE SLOPE
BAZADA
DEBRIS WASH PLAIN
DISSECTED EROSIONAL PLATEAU
GULLEY
PALAEO SAND DUNE
PEDIMENT ROCKY
PIEDMONT ZONE
ROCK FALL ZONE
VALLEY FILL BARREN
OTHER AREA
Project "WEGHARIS"

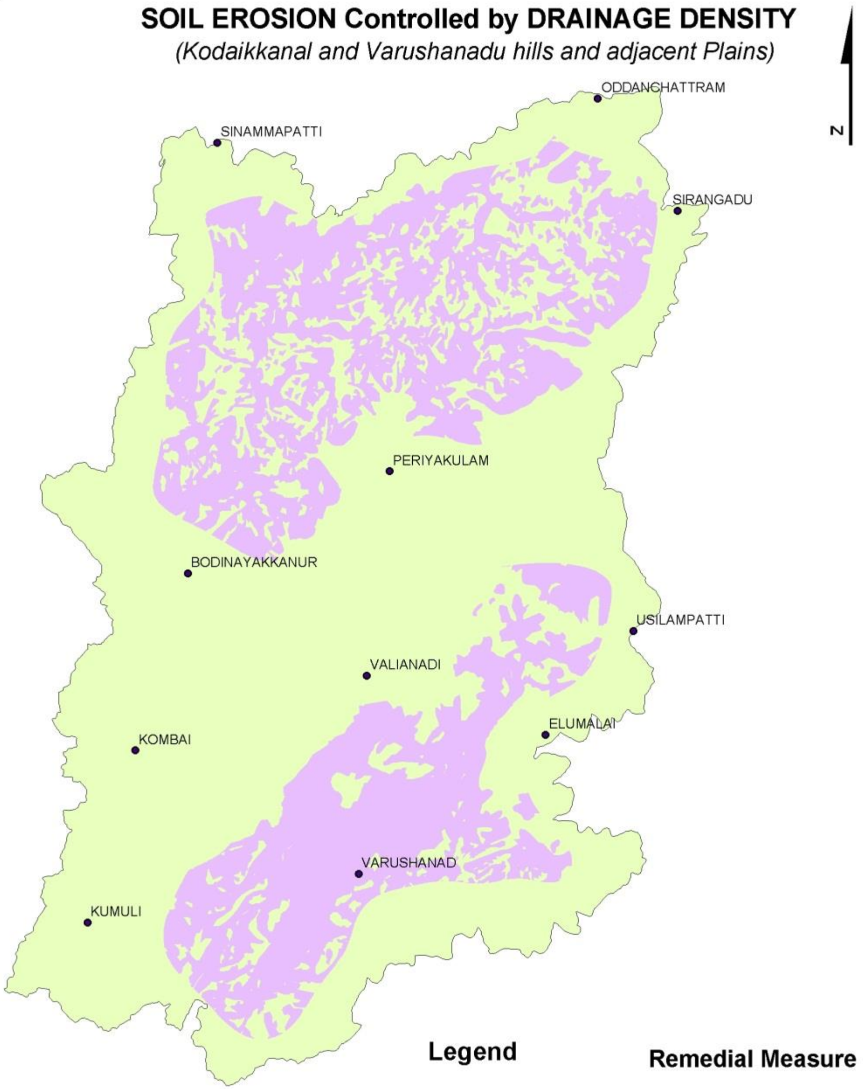
Fig. 4.13


Soil Erosion Controlled by Land Use/Cover
(Kodaikkanal and Varushanadu hills and adjacent Plains)
N
ODDANCHATTRAM
SINAMMAPATTI
SIRANGADU
PERIYAKULAM
BODINAYAKKANUR
USILAMPATTI
VALIANADI
ELUMALAI
KOMBAI
VARUSHANAD
KUMULI
Legend
Barren/Stony/Sheet
Fallow
ForestBlanks
LandwithoutScrub
Mining/Industrial/Waste
Openscrub
River/Streams
Sandy Area
Towns/Cities
Villages
Remedial Measure
- Aforestation
- Plantation/Horticulture
- Aforestation
- Aforestation
- Aforestation
- Aforestation
- Silt Trap/Check Dams
- Creepers
Project "WEGHARIS"
10 5 0 10 Kilometers


SOIL EROSION Controlled by SLOPE (more than 15%)
(Kodaikkanal and Varushanadu hills and adjacent Plains)
N
ODDANCHATTRAM
SINAMMAPATTI
SIRANGADU
PERIYAKULAM
BODINAYAKKANUR
USILAMPATTI
VALIANADI
ELUMALAI
KOMBAI
VARUSHANAD
KUMULI
Legend
Areas of Soil Erosion controlled by Slope (more than 15%)
Remedial Measure
- Contour Bunding
10 5 0 10 Kilometers
Project "WEGHARIS"

SOIL EROSION Controlled by DRAINAGE DENSITY

(Kodaikkanal and Varushanadu hills and adjacent Plains)



Legend

Areas of Soil Erosion controlled by Drainage Density

Remedial Measure

- Check Dams, Silt Traps and Grassed Water Ways

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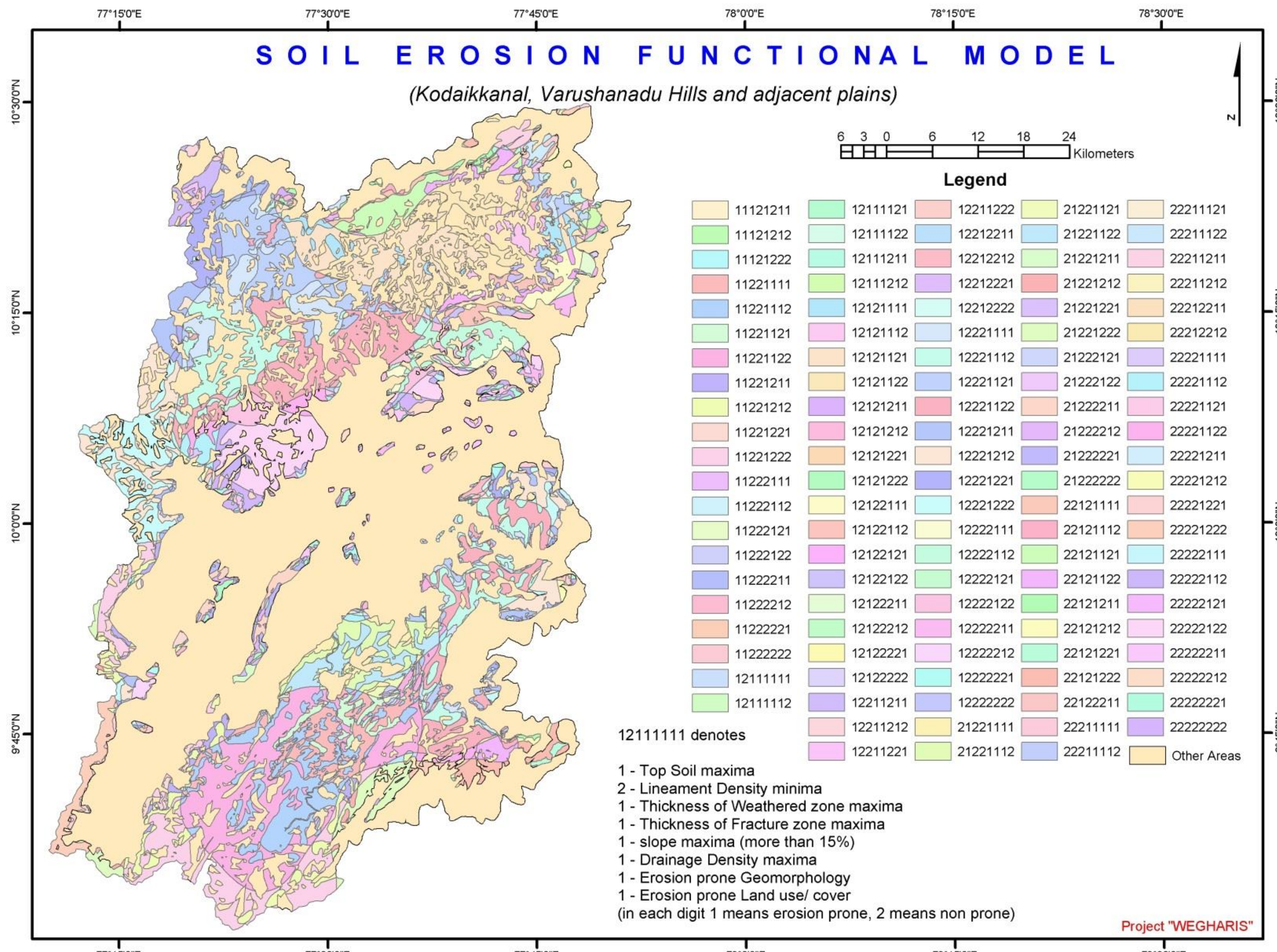


SOIL EROSION FUNCTIONAL MODEL
(Kodaikkanal, Varushanadu Hills and adjacent plains)
77°15'0"E
77°30'0"E
77°45'0"E
78°0'0"E
78°15'0"E
78°30'0"E
10°30'0"N
10°15'0"N
10°0'0"N
9°45'0"N
N
6 3 0 6 12 18 24
Kilometers
Legend
11121211
11121212
11121222
11221111
11221112
11221121
11221122
11221211
11221212
11221221
11221222
11222111
11222112
11222121
11222122
11222211
11222212
11222221
11222222
12111111
12111112
12111121
12111122
12111211
12111212
12121111
12121112
12121121
12121122
12121211
12121212
12121221
12121222
12122111
12122112
12122121
12122122
12122211
12122212
12122221
12122222
12211211
12211212
12211221
12211222
12212211
12212212
12212221
12212222
12221111
12221112
12221121
12221122
12221211
12221212
12221221
12221222
12222111
12222112
12222121
12222122
12222211
12222212
12222221
12222222
21221111
21221112
21221121
21221122
21221211
21221212
21221221
21221222
21222121
21222122
21222211
21222212
21222221
21222222
22121111
22121112
22121121
22121122
22121211
22121212
22121221
22121222
22122211
22211111
22211112
22211121
22211122
22211211
22211212
22212211
22212212
22221111
22221112
22221121
22221122
22221211
22221212
22221221
22221222
22222111
22222112
22222121
22222122
22222211
22222212
22222221
22222222
Other Areas
12111111 denotes
1 - Top Soil maxima
2 - Lineament Density minima
1 - Thickness of Weathered zone maxima
1 - Thickness of Fracture zone maxima
1 - slope maxima (more than 15%)
1 - Drainage Density maxima
1 - Erosion prone Geomorphology
1 - Erosion prone Land use/ cover
(in each digit 1 means erosion prone, 2 means non prone)
Project "WEGHARIS"

Fig. 4.17

The Detailed Site Suitable Remedial Measures

Sl.No	SOIL EROSION CONTROLLED BY	REMEDIAL MEASURES
1	Drainage density	Gully Plugging, Check Daming
2	Slope	Check dam
3	Geomorphology	Gully Plugging, Afforestation, Silt trapping
4	Land Use / Land Cover	Afforestation in forest blank /open forest
5	Lineament Density	Gully filled Vegetation, Check daming
6	Drainage Density very High + Lineament Density Very High+ Bazada	Afforestation, Gully plugging, Gully Filled vegetation and Check daming
7	Drainage Density very High + Lineament Density Very High+ Valley fill	Afforestation, Gully Filled vegetation, gully plugging, Check dam, silt trap
8	Drainage Density very High + Lineament Density Very High+ Steep Slope	Placement of netting, gully filled vegetations, geotextiling, drainage diversion, surface and subsurface drains
9	Drainage Density very High + Lineament Density Very High+ Moderate Slope	Afforestation, Gully Filled vegetation, gully plugging, Check dam, silt trap and grassed water ways
10	Drainage Density very High + Lineament Density Very High+ Active Slope	Placement of netting, gully filled vegetations, geotextiling and silt trapping
11	Drainage Density very High + Lineament Density High+ Convex Slope	Grassed water ways, afforestation
12	Drainage Density Moderate + Lineament Density Moderate + Steep Slope	Afforestation, gully plugging, flattening of the slope, turfing with the soil binders among the grasses
13	Drainage Density Moderate + Lineament Density Very High+ Bazada + Scrub Land +Steep Slope	Plantation of Deep penetrating root, protection wall with weep wholes

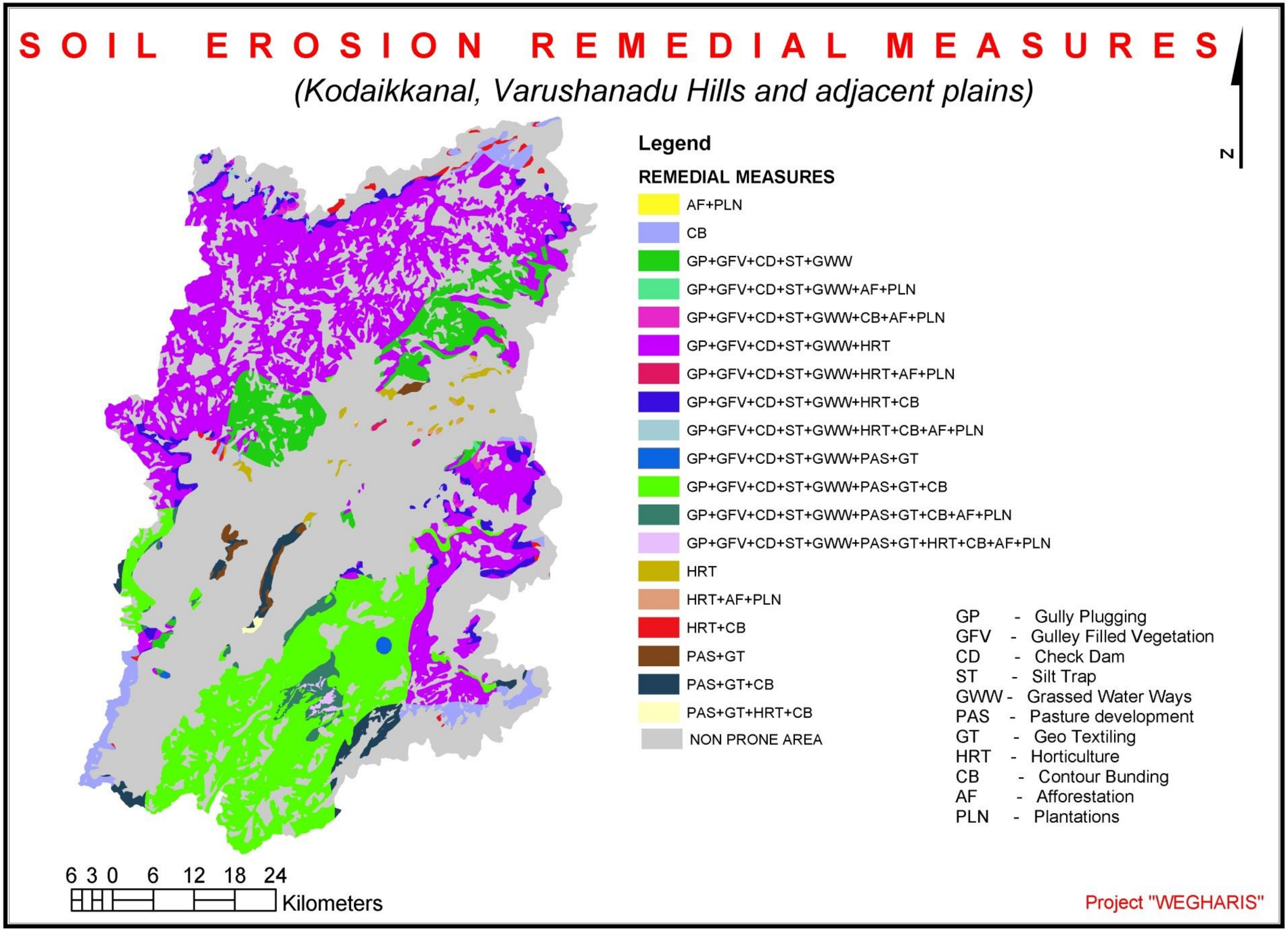

SOIL EROSION REMEDIAL MEASURES
(Kodaikkanal, Varushanadu Hills and adjacent plains)
N
Legend
REMEDIAL MEASURES
AF+PLN
CB
GP+GFV+CD+ST+GWW
GP+GFV+CD+ST+GWW+AF+PLN
GP+GFV+CD+ST+GWW+CB+AF+PLN
GP+GFV+CD+ST+GWW+HRT
GP+GFV+CD+ST+GWW+HRT+AF+PLN
GP+GFV+CD+ST+GWW+HRT+CB
GP+GFV+CD+ST+GWW+HRT+CB+AF+PLN
GP+GFV+CD+ST+GWW+PAS+GT
GP+GFV+CD+ST+GWW+PAS+GT+CB
GP+GFV+CD+ST+GWW+PAS+GT+CB+AF+PLN
GP+GFV+CD+ST+GWW+PAS+GT+HRT+CB+AF+PLN
HRT
HRT+AF+PLN
HRT+CB
PAS+GT
PAS+GT+CB
PAS+GT+HRT+CB
NON PRONE AREA
GP - Gully Plugging
GFV - Gulley Filled Vegetation
CD - Check Dam
ST - Silt Trap
GWW - Grassed Water Ways
PAS - Pasture development
GT - Geo Textiling
HRT - Horticulture
CB - Contour Bunding
AF - Afforestation
PLN - Plantations
6 3 0 6 12 18 24
Kilometers
Project "WEGHARIS"

Fig. 4.18

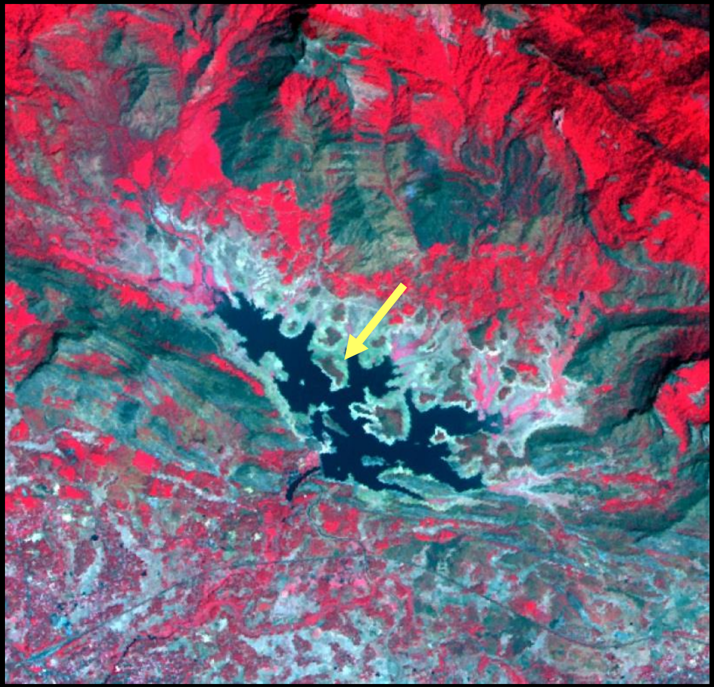
RESERVOIR SILTATION

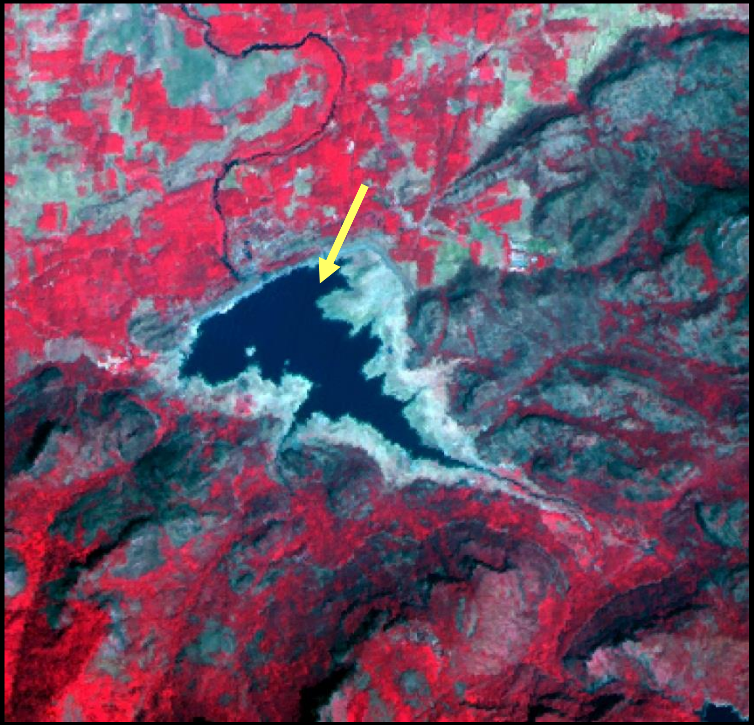
Identify silted reservoirs / tanks

Identify areas of soil erosion / silt supply

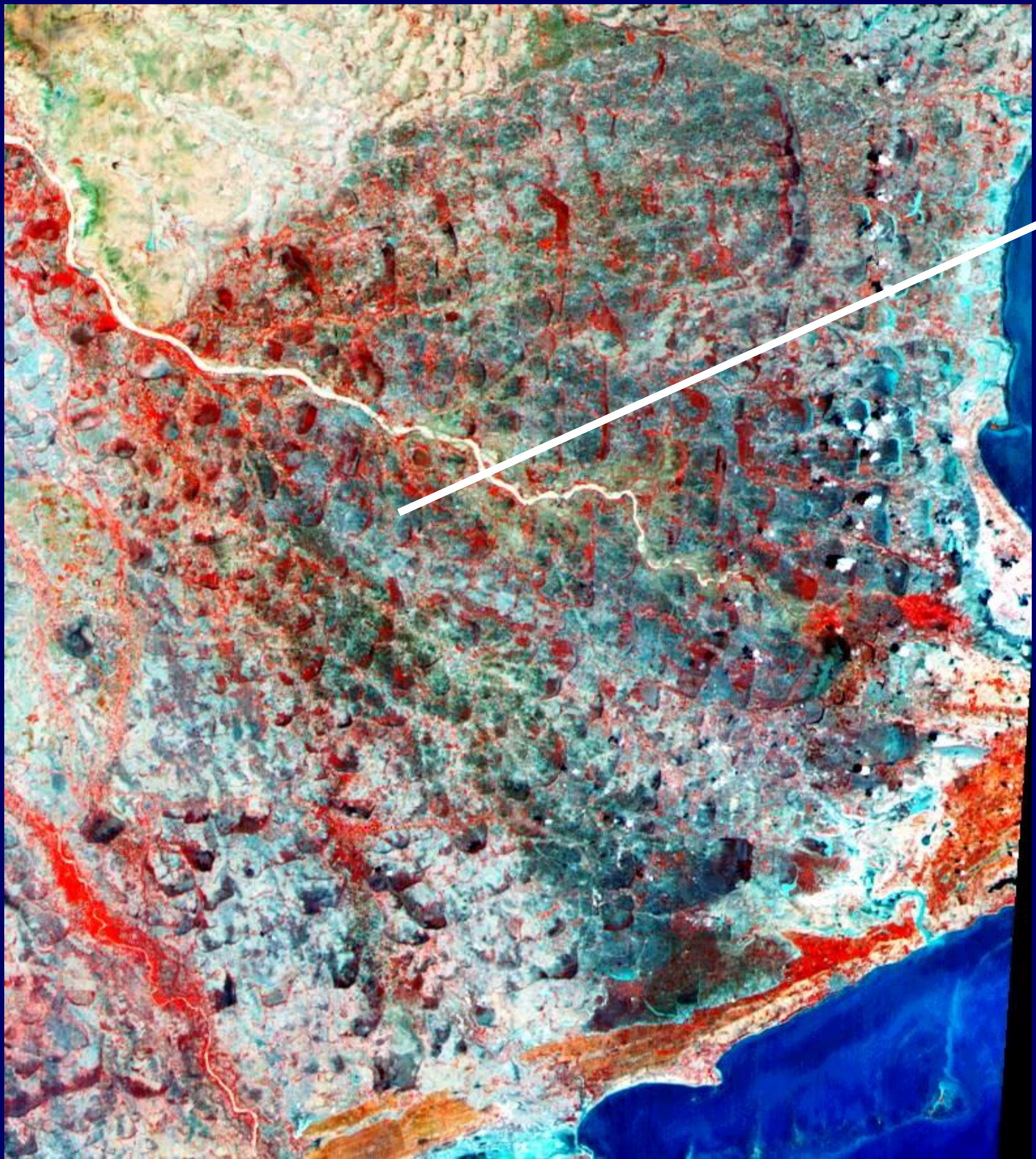
Suggest remedial measures to arrest soil erosion in the catchment itself.

Silted foot hill Water Bodies



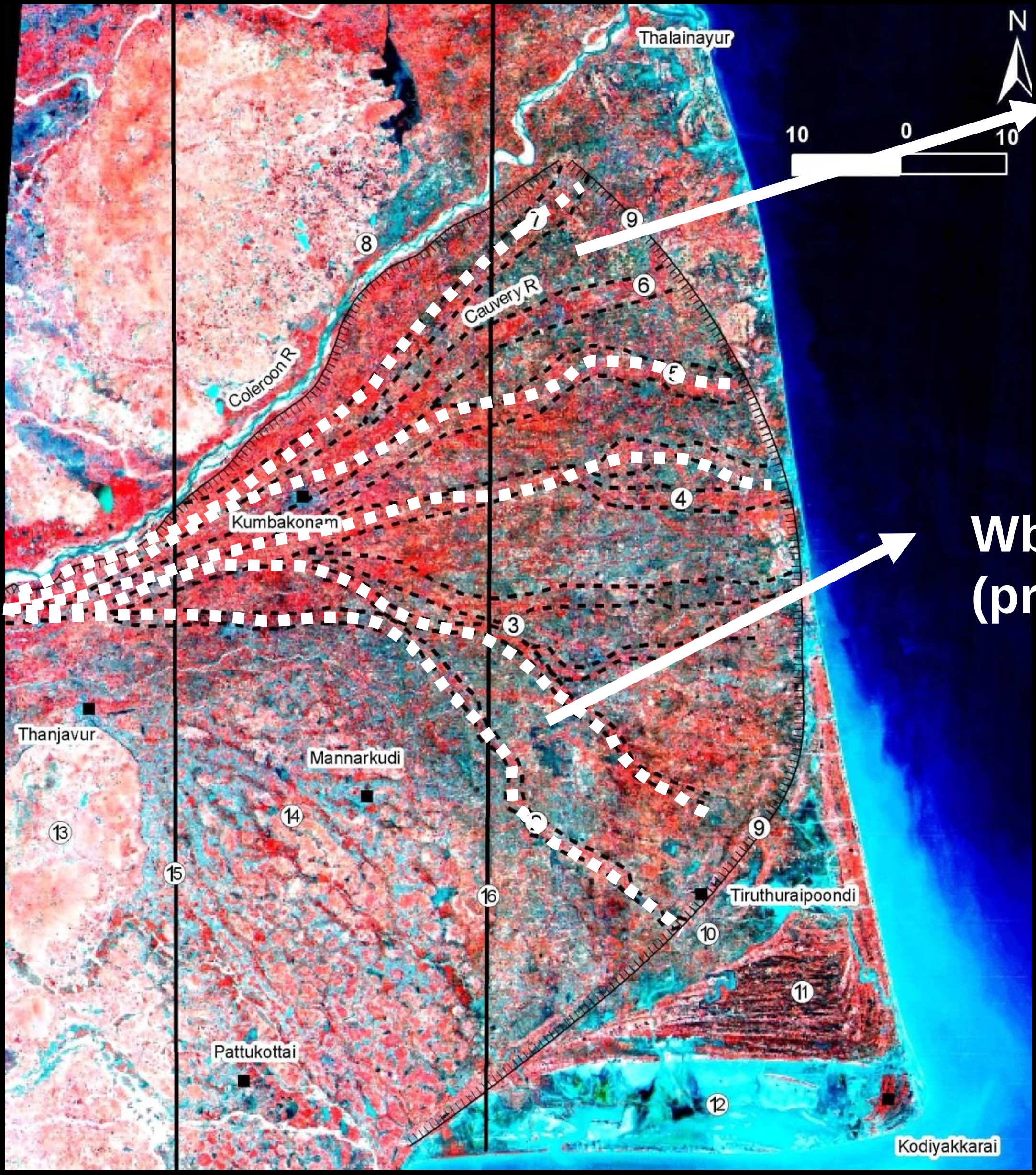


Lobate Delta – Vaigai



Water bodies lobate Deltas prone for heavy siltation

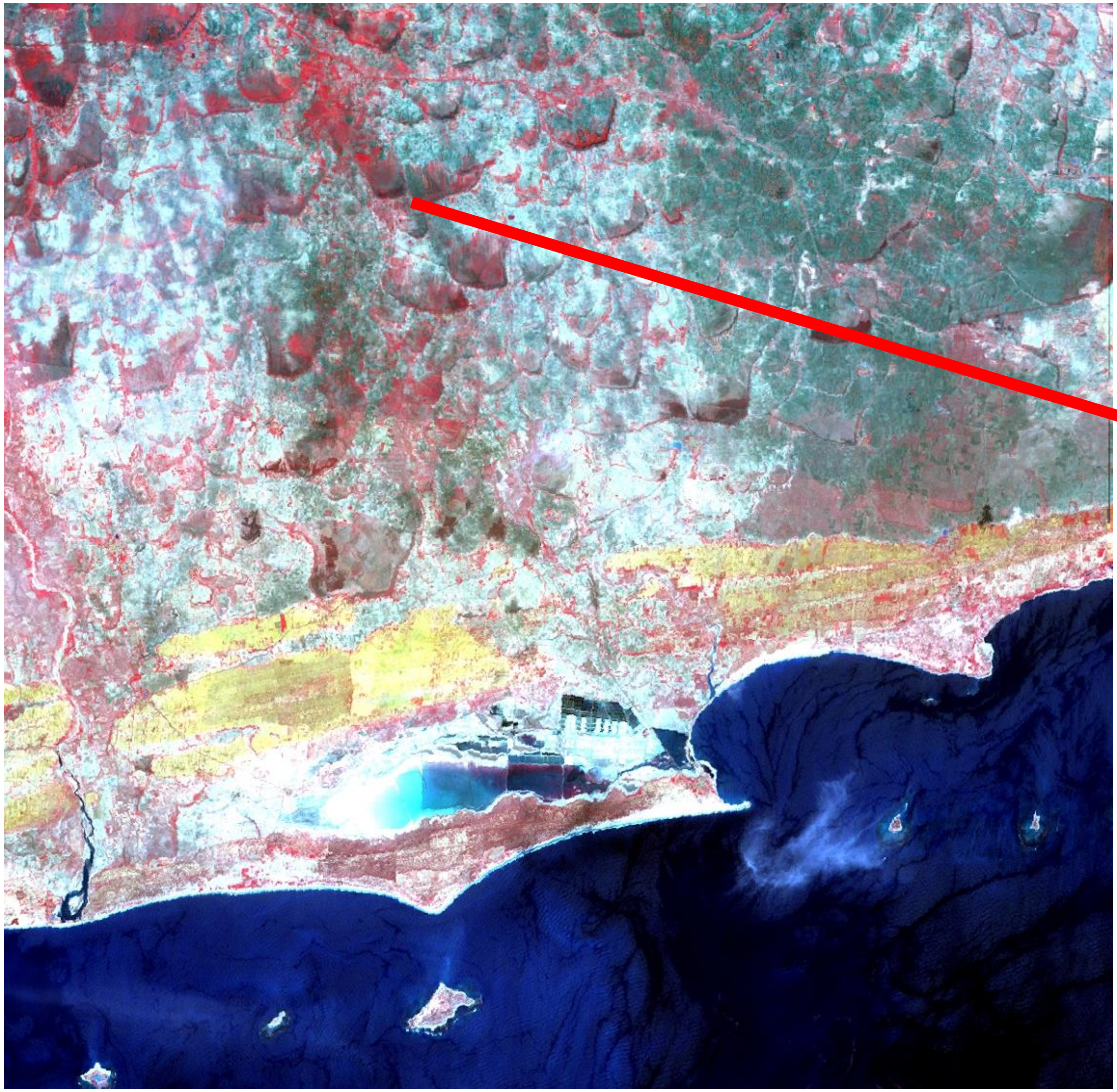
Arcuate delta - Cauvery



Wbs of active deltas (prone for water logging

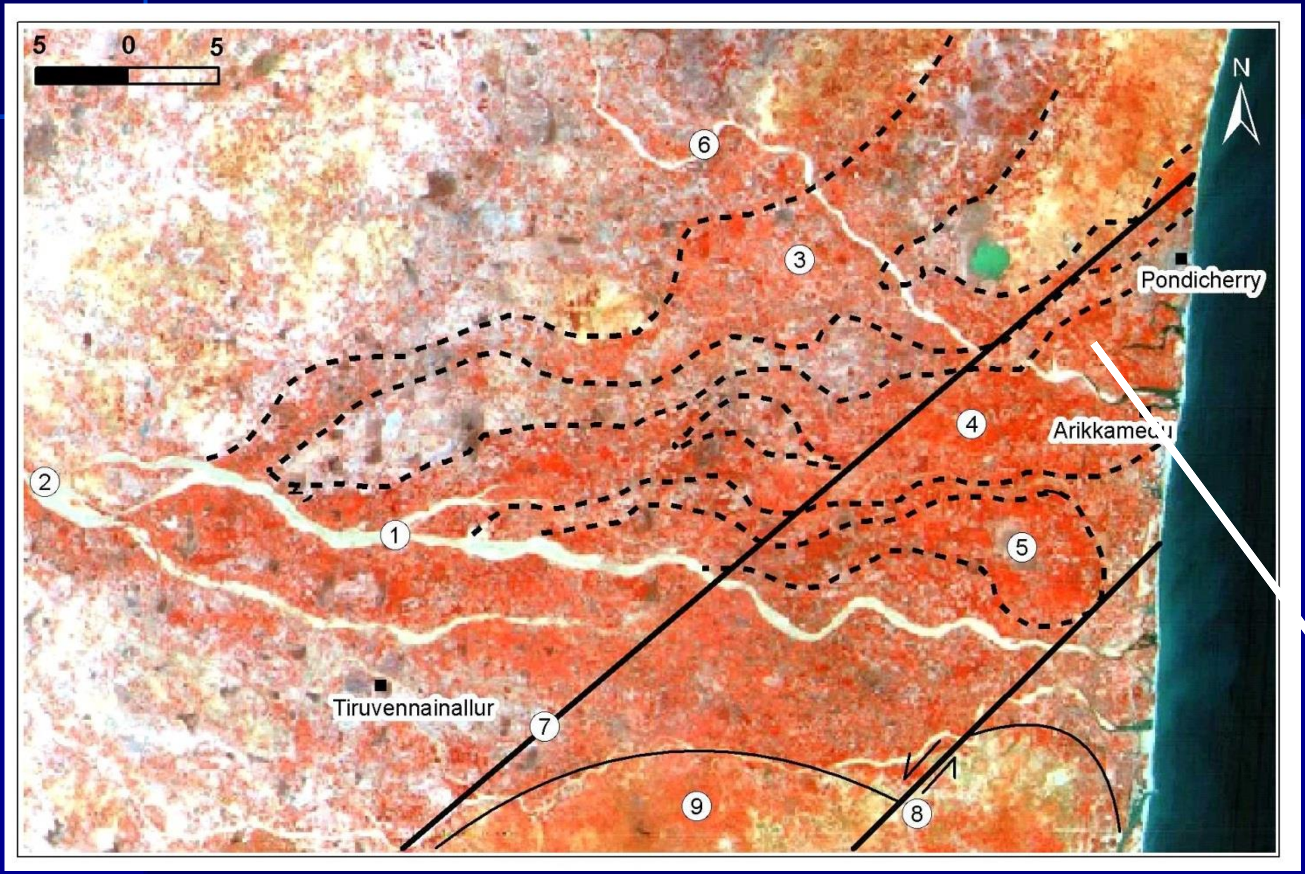
Wbs of abandoned delta (prone for defunct)

Cuspate delta - Vaigai Pro Delta Region



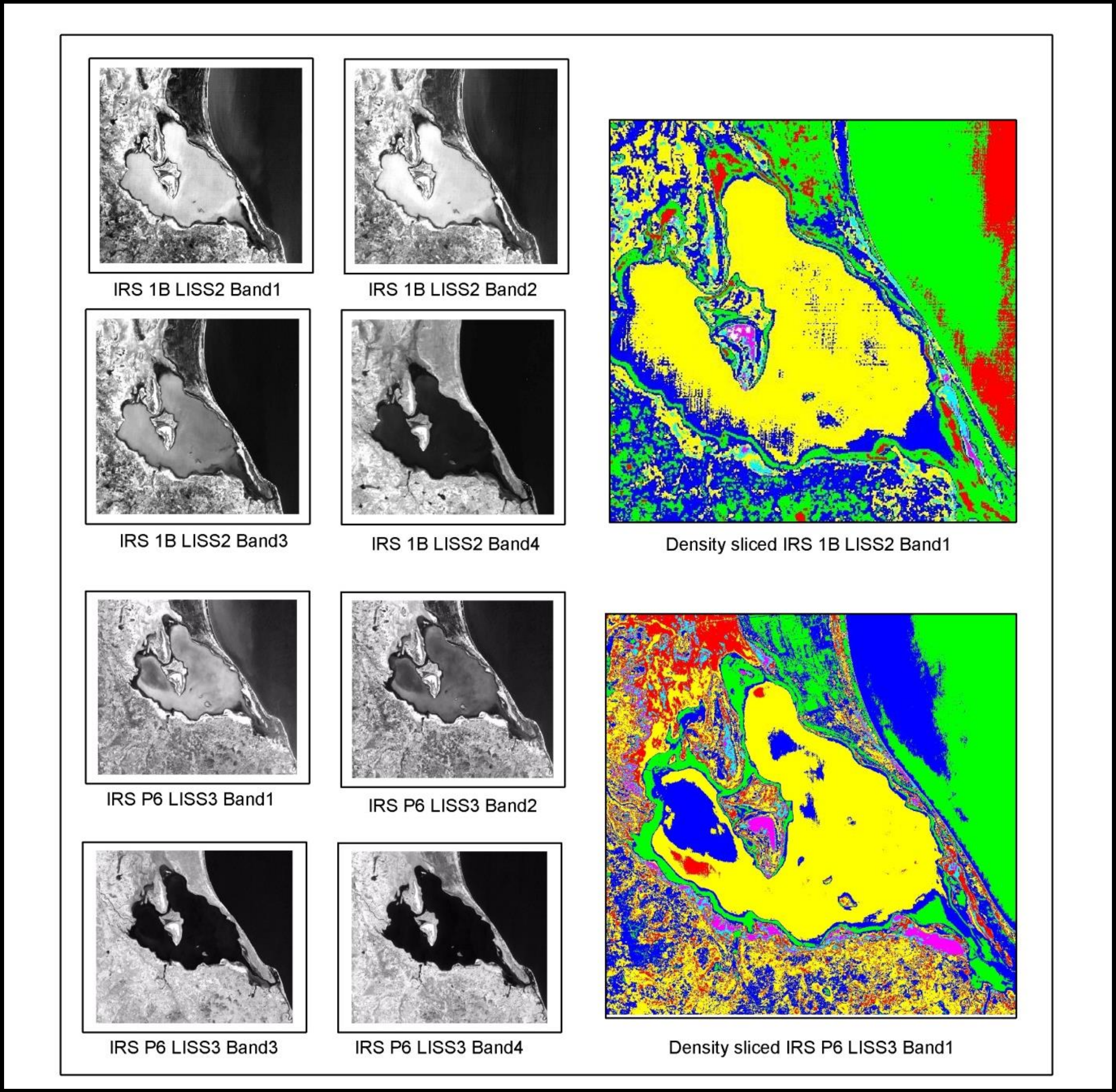
Wbs cuspate deltas prone for Water logging & flooding

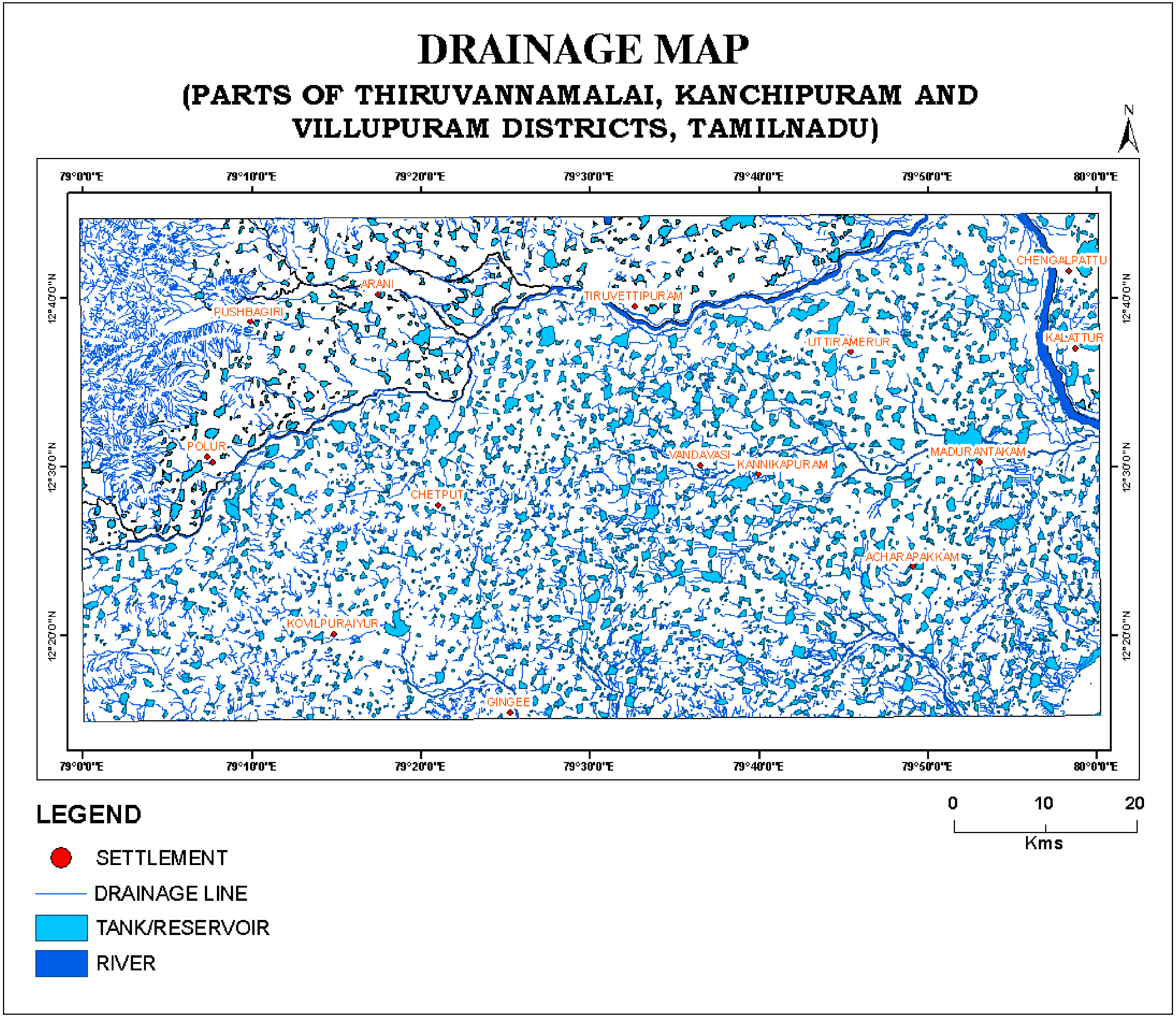
Digitate Delta - Ponnaiyar



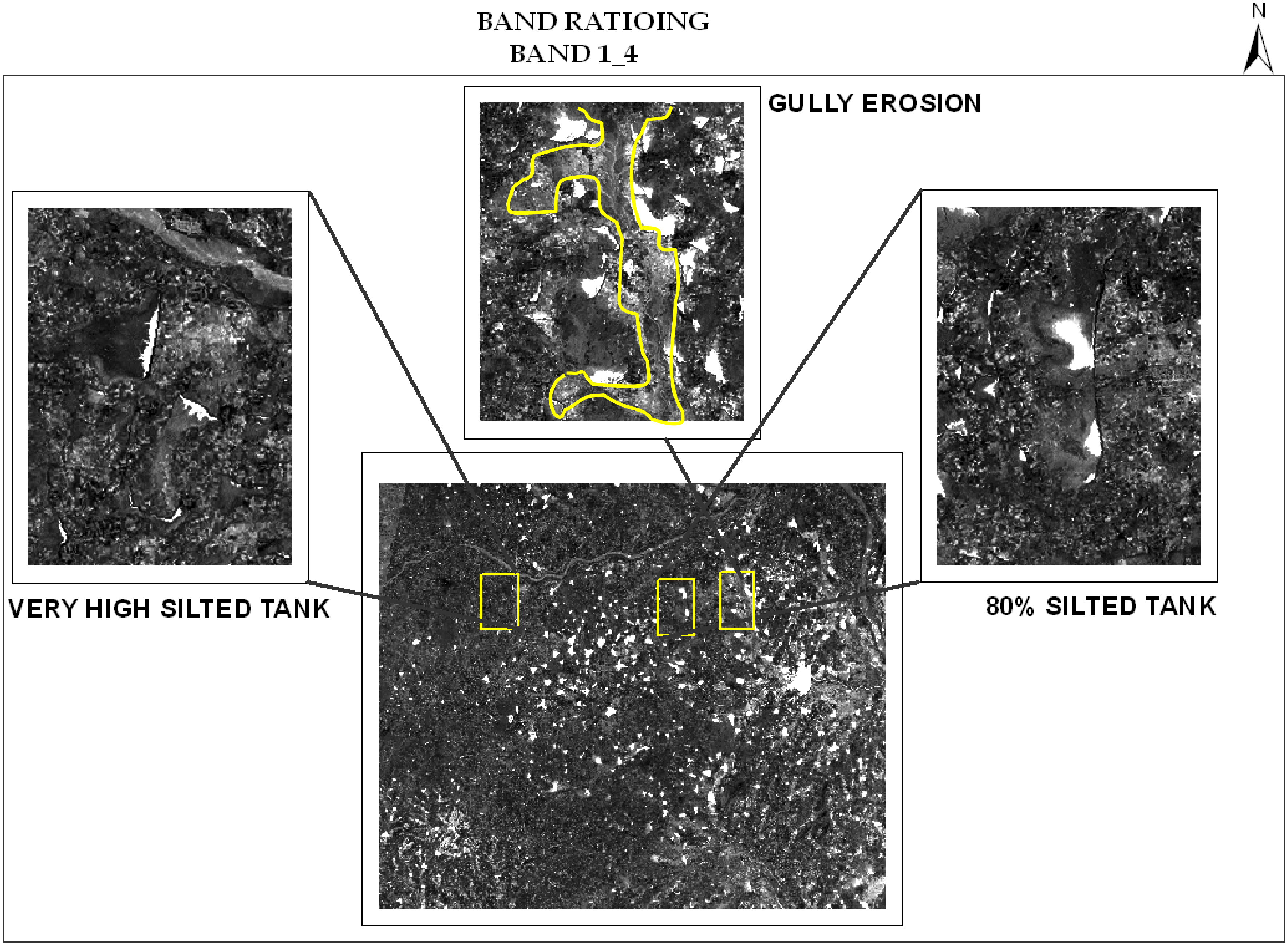
Digitate delta WBs prone for salt water incursion

Silt choking in Pulicat lake due to catchment uplifts , soil erosion and Silt supply

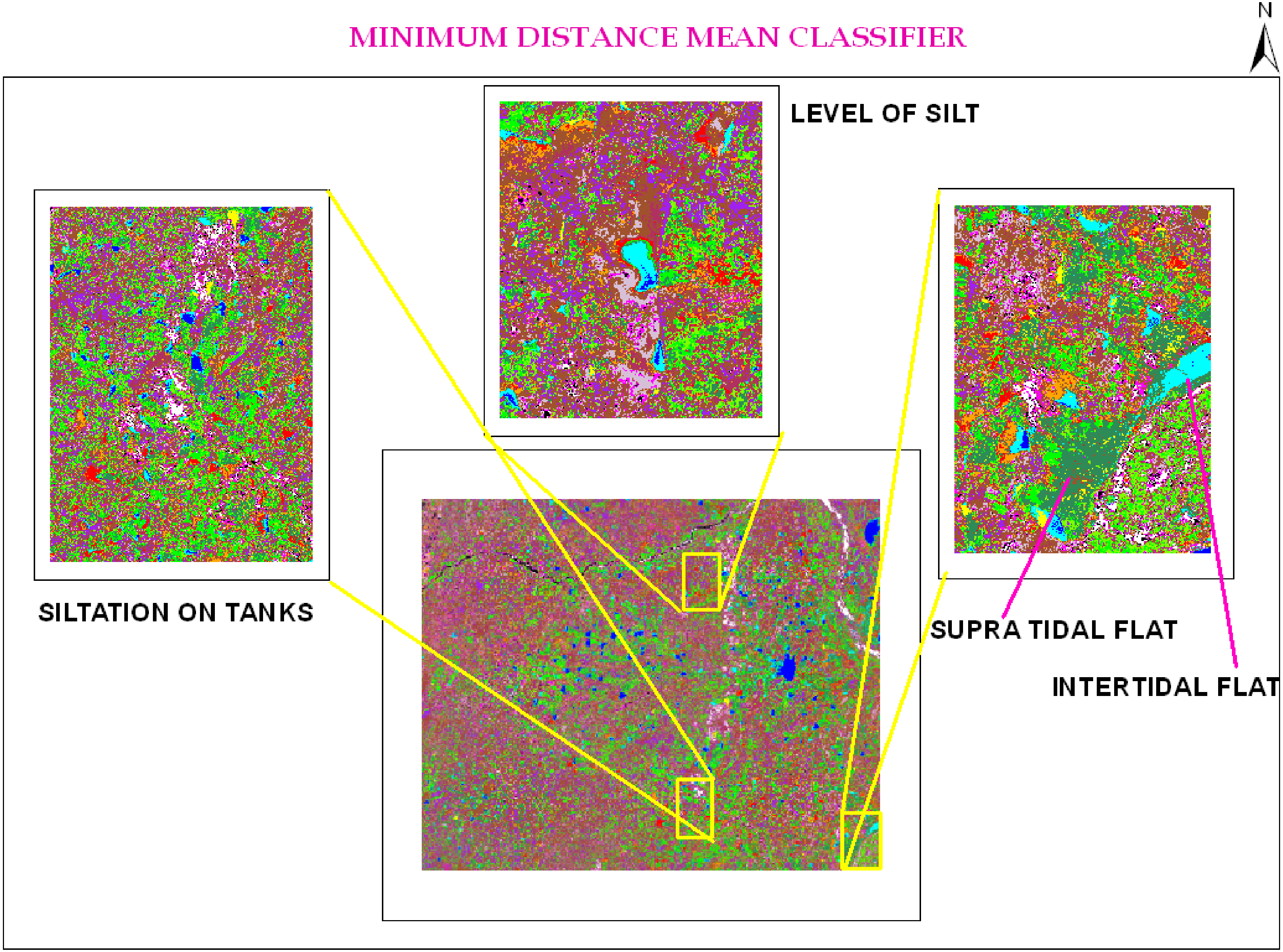



DRAINAGE MAP
(PARTS OF THIRUVANNAMALAI, KANCHIPURAM AND VILLUPURAM DISTRICTS, TAMILNADU)
N
79°0'0"E
79°10'0"E
79°20'0"E
79°30'0"E
79°40'0"E
79°50'0"E
80°0'0"E
12°40'0"N
12°30'0"N
12°20'0"N
CHENGALPATTU
ARANI
TIRUVETTIPURAM
PUSHBAGIRI
KALATTUR
UTTIRAMERUR
POLUR
VANDAVASI
KANNIKAPURAM
MADURANTAKAM
CHETPUT
ACHARAPAKKAM
KOVILPURAIYUR
GINGEE
LEGEND
SETTLEMENT
DRAINAGE LINE
TANK/RESERVOIR
RIVER
0
10
20
Kms

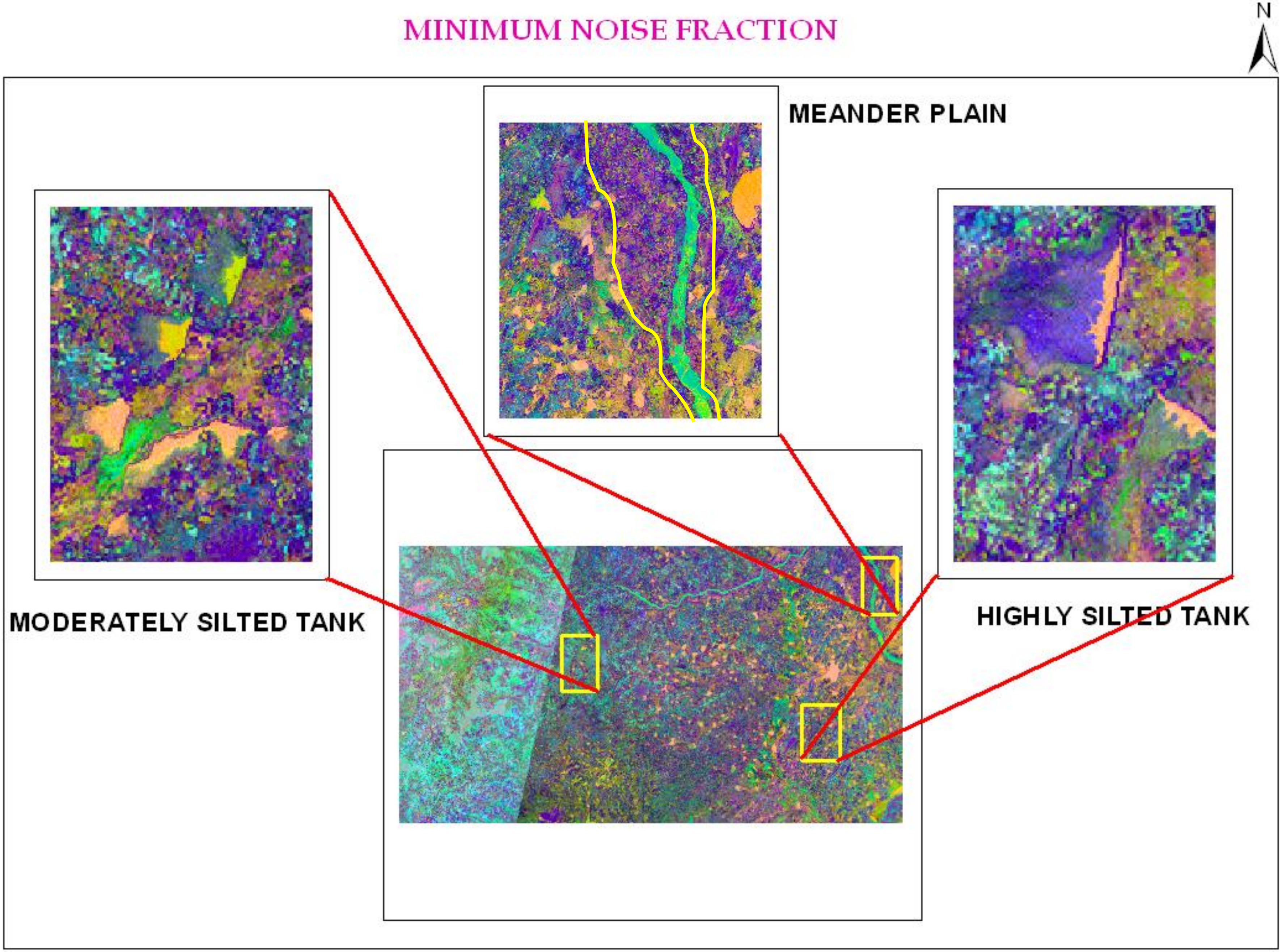
BAND RATIOING
BAND 1_4



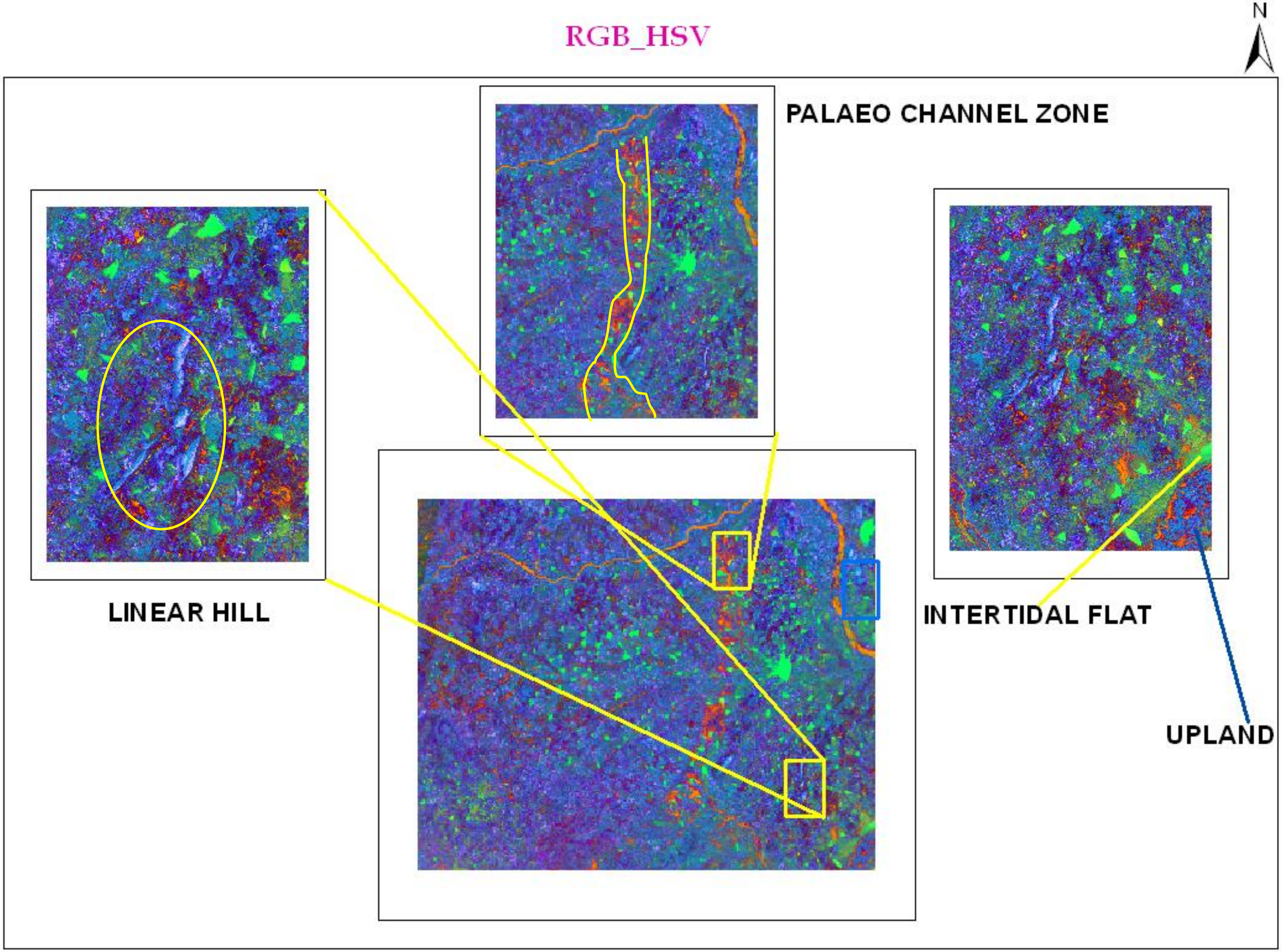
MINIMUM DISTANCE MEAN CLASSIFIER



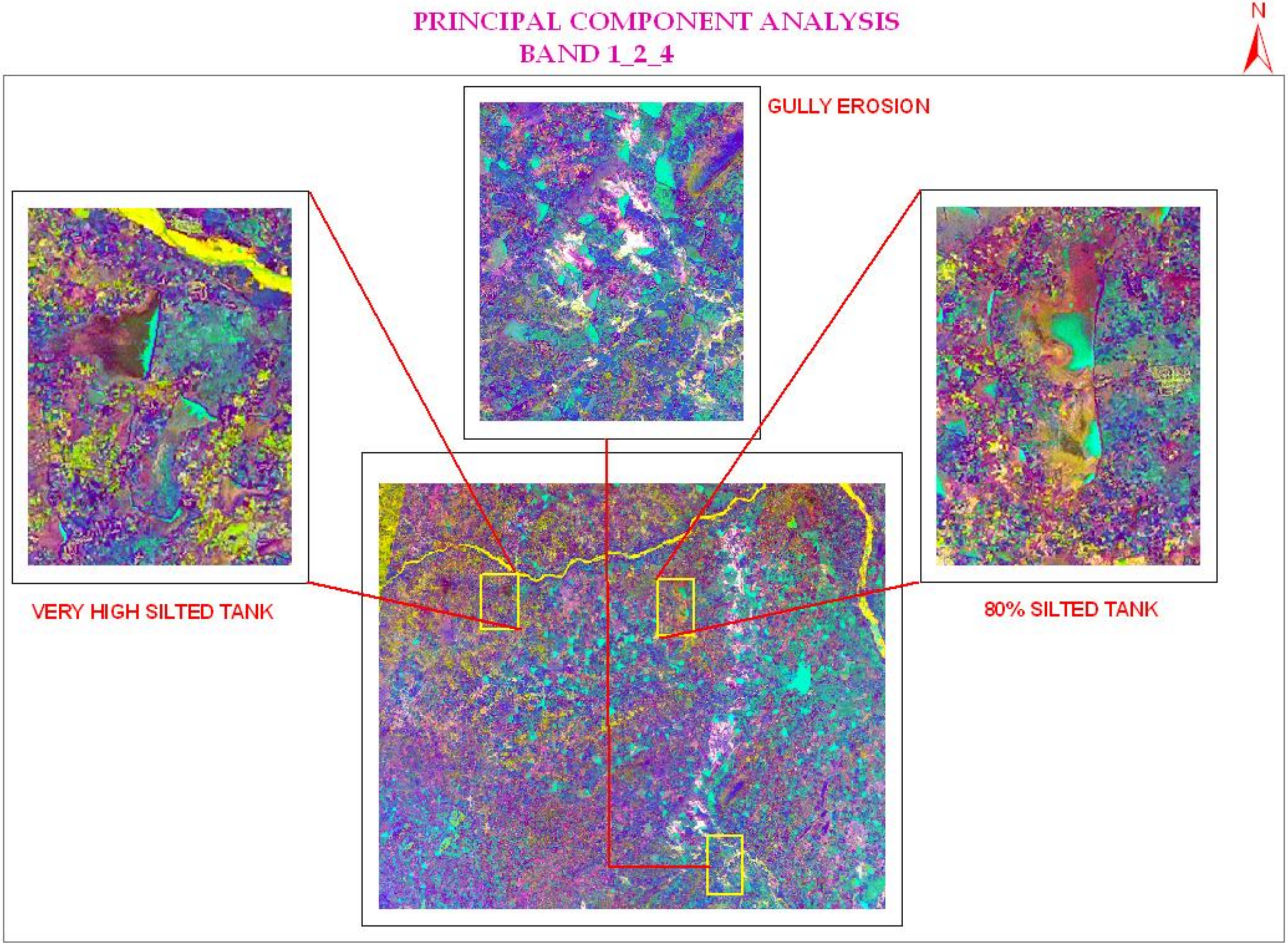
MINIMUM NOISE FRACTION



RGB_HSV



PRINCIPAL COMPONENT ANALYSIS
BAND 1_2_4



(1) TOTALLY DEFUNCT AND VEGETATED

(2) TOTALLY DEFUNCT TANK

(3) DESILTED FISH FARM

(4) SILT TRAP

(5)RESERVOIR OUTLET

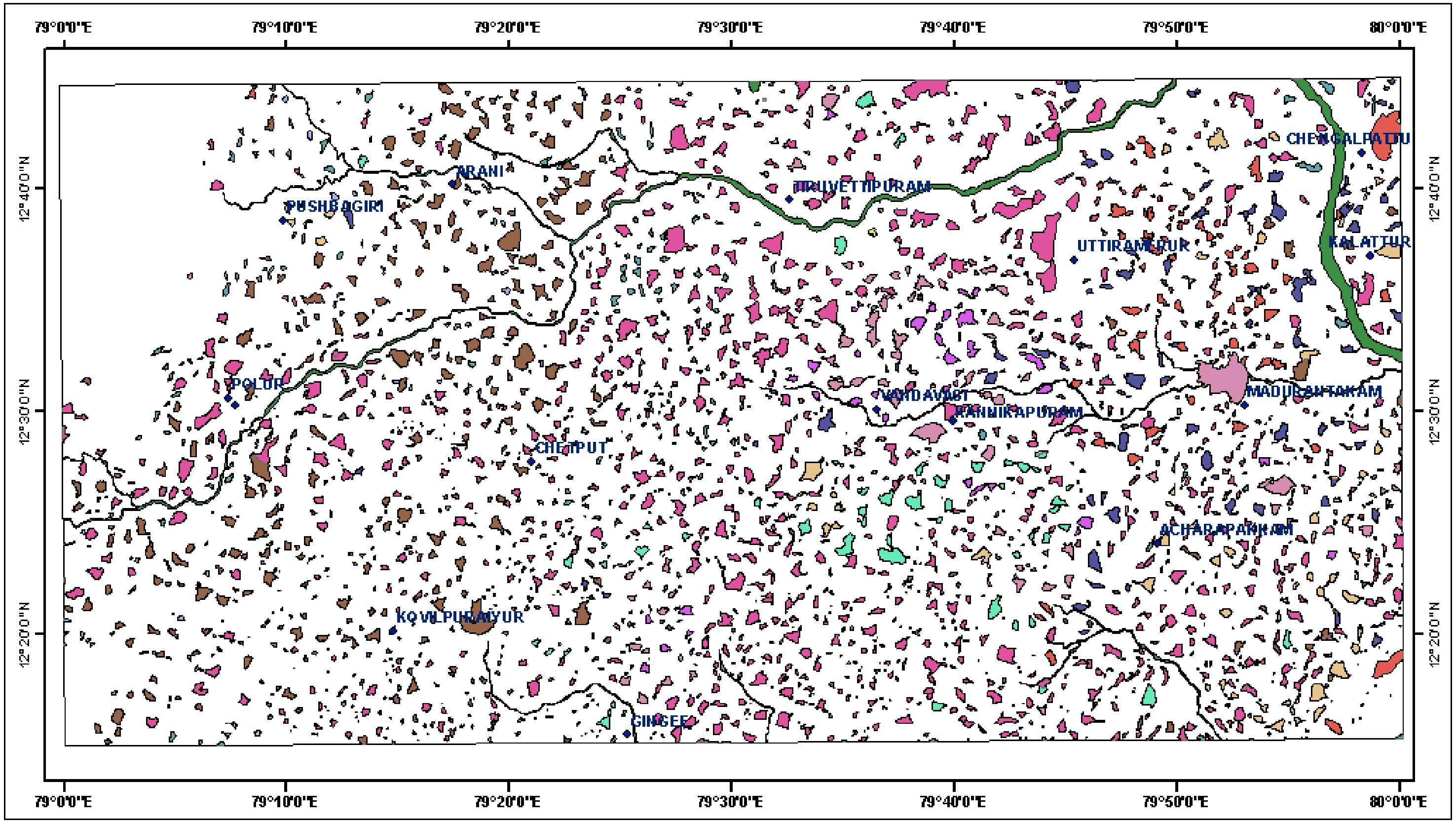
(6)CONSTRUCTED BUND

(7)HAND AUGER DRILL

(8)SILT THICKNESS

SILT LEVEL MAP

(PARTS OF THIRUVANNAMALAI, KANCHIPURAM AND VILLUPURAM DISTRICTS, TAMILNADU)



LEGEND

- SETTLEMENT
- RIVER
- TOTALLY DEFUNCT TANK
- TOTALLY DEFUNCT VEGETATED
- 80-100% SILTED
- 80-100% SILTED VEGETATED
- 60-80% SILTED
- 60-80% SILTED VEGETATED
- 40-60% SILTED
- 40-60% SILTED VEGETATED
- 20-40% SILTED
- 20-40% SILTED VEGETATED
- <20% SILTED

0 10 20
Kms

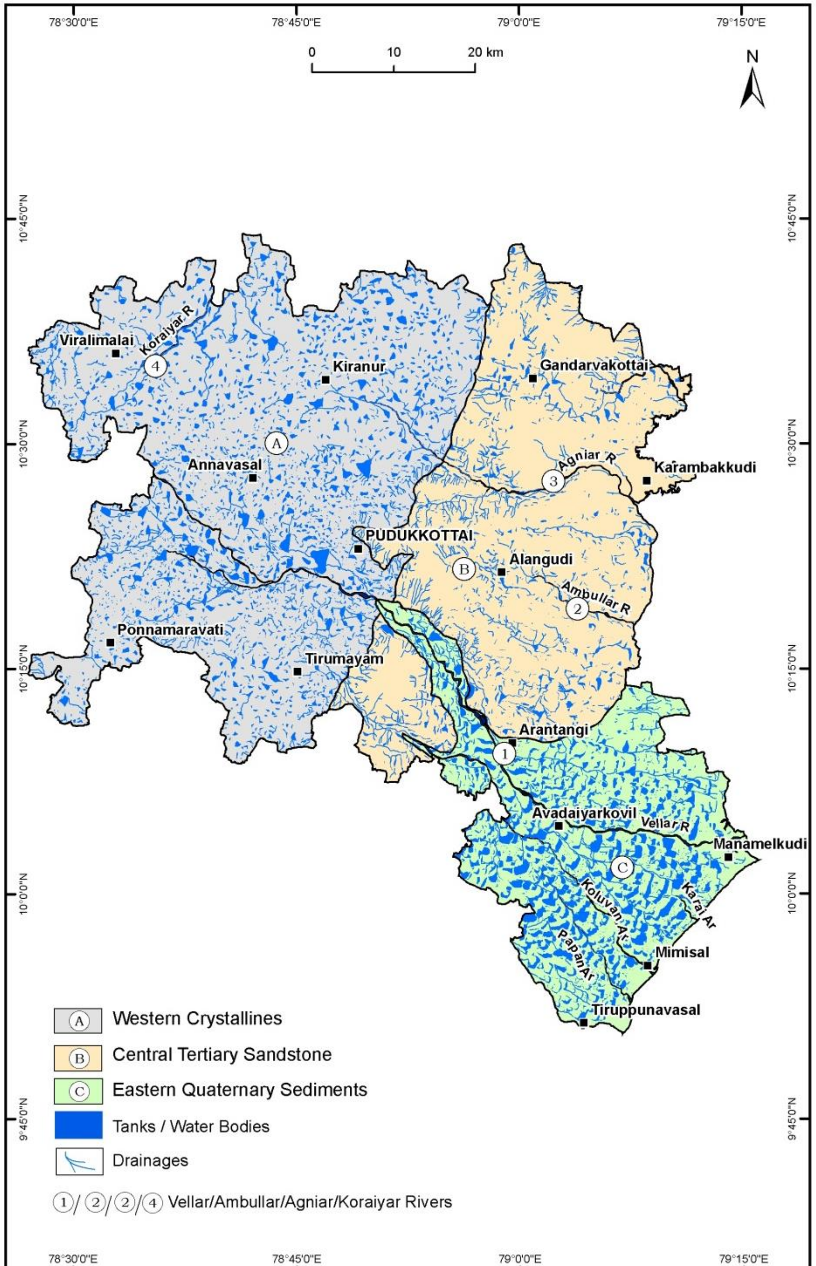


Fig. 5.1. Drainages and Tanks - Pudukkottai District

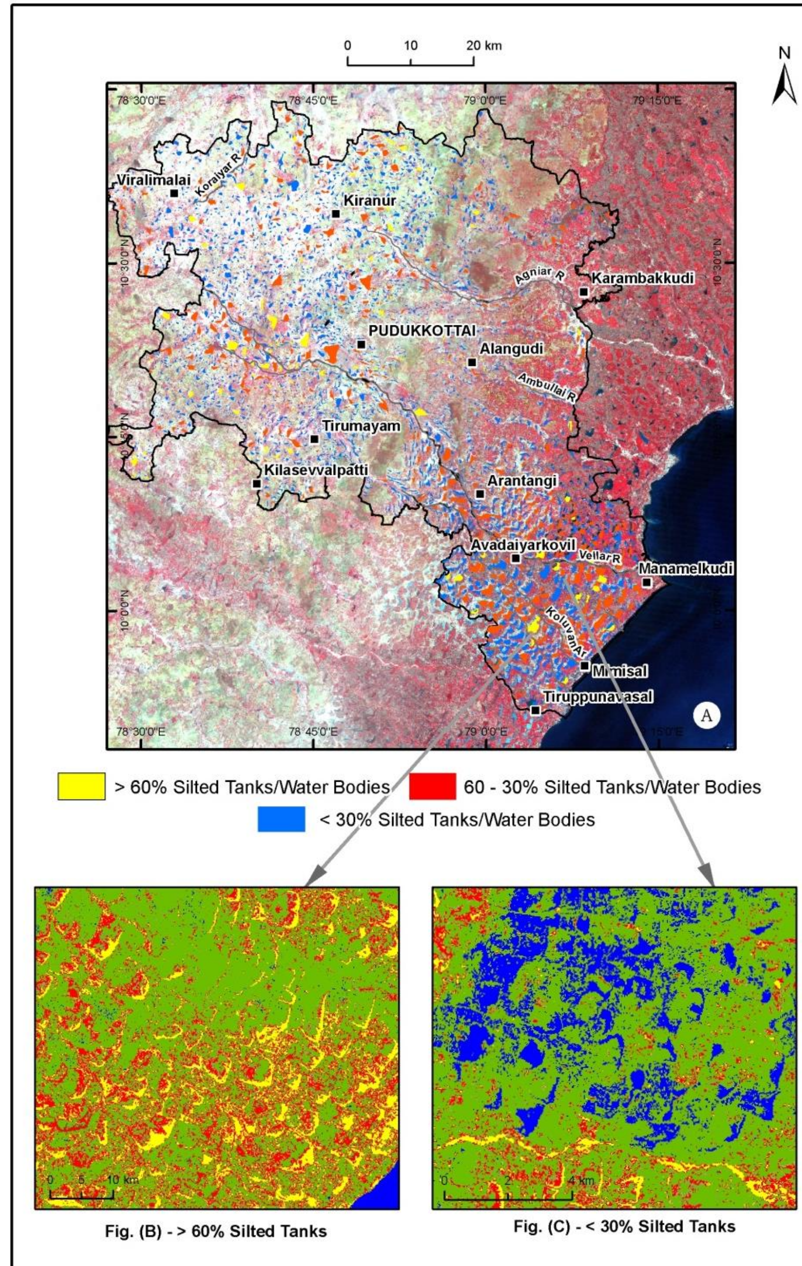


Fig. 5.2 IRS FCC (A) and Density Sliced (B and C) Images showing Silted Water Bodies

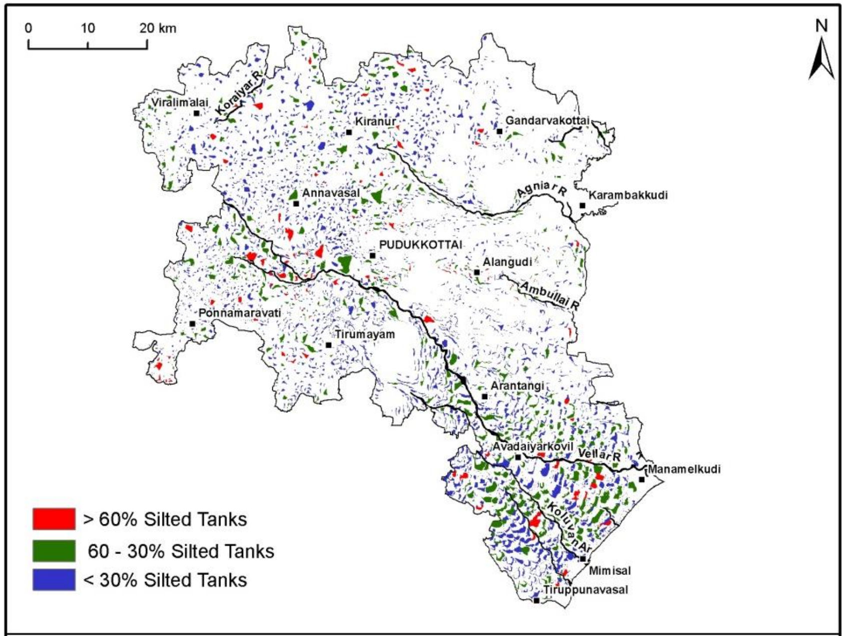


Fig. 6.22 Silted Tanks/Water Bodies

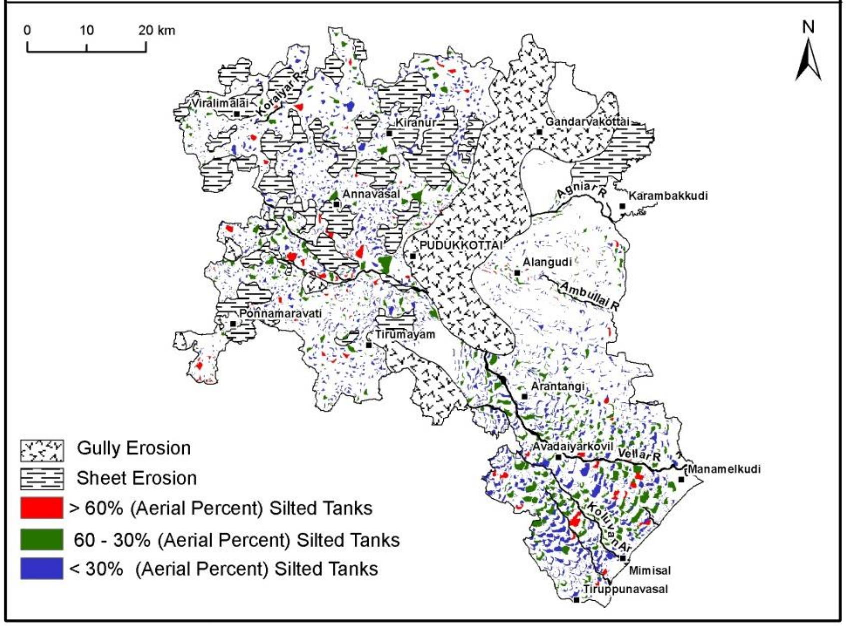


Fig. 6.23 Silted Tanks/Water Bodies - Gully and Sheet Erosion

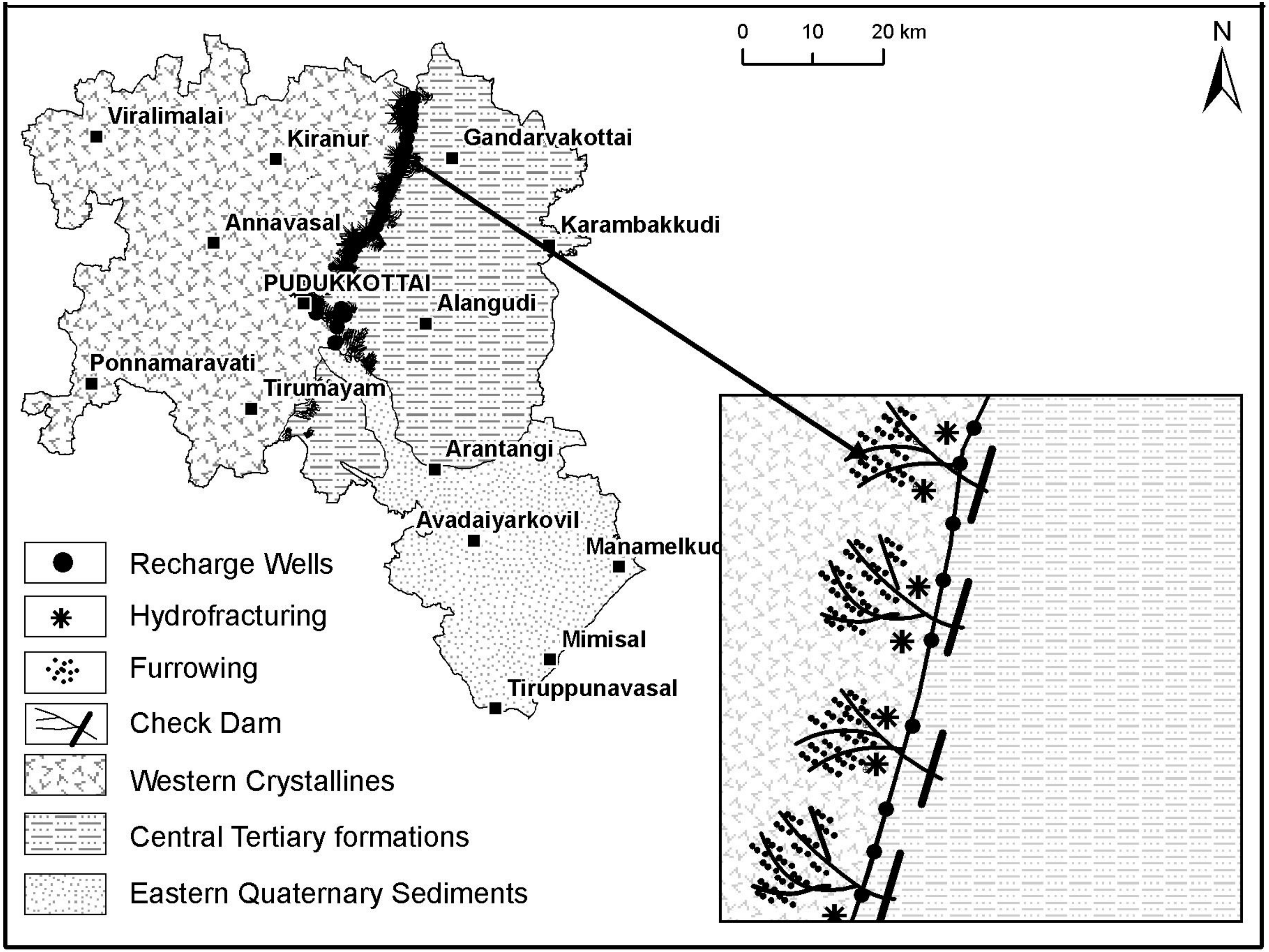


Fig.6.35 Check Dams in Upland