

Use of Remote Sensing and GIS in Volcanic Eruption

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Abstract: *Volcano is a vent or opening in the earth's crust through which molten material erupts suddenly. Vulcanicity includes all those processes and mechanisms which are related to the origin of magmas, gases and vapour, their ascent and appearance on the earth's surface in various forms. Volcanic materials discharged during eruption include gases and vapour, lavas, fragmental materials and ashes. Before an eruption happens, magma moves up towards the ground surface. Volcanologists use several methods to detect the movement of magma like detecting earthquakes, measuring ground deformation, monitoring of volcanic gases, monitoring changes in the chemistry and temperature of greater lakes.*

Keywords: Remote Sensing (RS), Geographical Information System (GIS), Volcanic Gases, Volcanic Eruption, Mount St. Helen, Montana (USA), monitoring of Volcanic Eruption.

1. Introduction

Any natural opening in the earth's crust, called a fissure, where melted rock, ash, gases and steam come out is called volcano. Volcanoes look like mountains, but they are really flat land that is pushed upward because of the pressure below the earth. The pressure comes from hot magma and gases that built up below the earth's surface that work up to the surface through cracks in the earth's plate. As it is forced up to the surface, the gases and magma push the earth up with it forming the mountain shape. When the magma gets near the surface of the earth, it sometimes erupts violently, but can also erupt also without violence. Volcanoes are hot always erupting. Sometime they lie quietly for thousands of years in between eruptions. Some volcanoes have areas around them that experience earthquakes and release gases, but they do not erupt with magma.

2. Volcano

The terms volcano, mechanism of volcanoes and vulcanicity are more or less synonym to common man but these have different connotations in geology and geography. Vulcanicity includes all those processes and mechanisms which are related to the origin of magmas, gases and vapour, their ascent and appearance on the earth's surface in various forms. The vulcanicity has two components which operate below the crustal surface and above the crust. The endogenetic mechanism of vulcanicity includes the creation of hot and liquid magmas and gases in the mantle and the crust, their expansion and upward ascent, their intrusion, cooling and solidification in various forms below crustal surface (for example: batholiths, laccoliths, sills, dykes, lopoliths, phacoliths etc.) While the exogenous mechanism

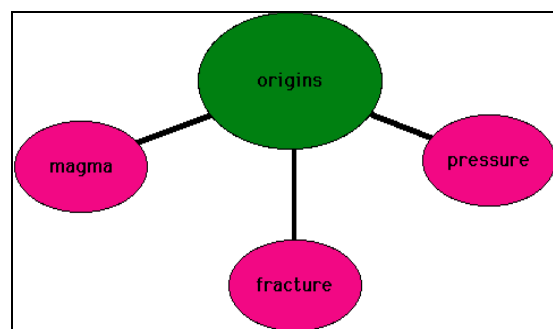


Figure 1: Origin of Volcano

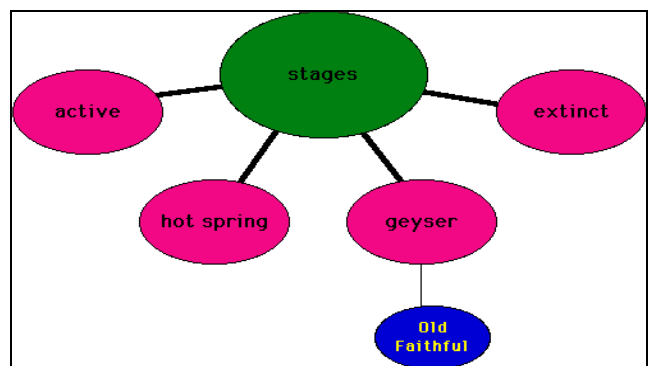


Figure 2: Stages of Volcano

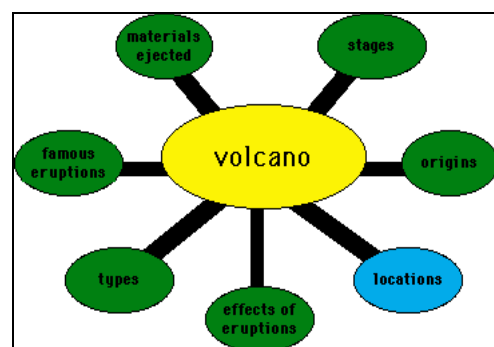


Figure 3: Volcano

Includes the process of appearance of lava, volcanic dust and ashes, fragmental material, mud, smoke etc. (Figure 1, 2, 3)

A volcano is vent or opening usually circular or nearly circular in form, through which heated materials consisting of gases, water, liquid lava and fragments of rocks are ejected from the highly heated interior to the surface of the earth.

3. Components of volcanoes

3.1 Volcanic cones or simply volcanic mountains:-

Volcanoes are explosive type or central eruption types are associated with the accumulated volcanic materials in the form of cones which are called volcanic cones.

3.2 Volcanic hole or vent

Volcanic materials are like magma, gases, ashes etc. are ejected on the earth surface from a hole.

3.3 Volcanic pipe

Volcanic vent or mouth which is connected with the interior part of the earth by a narrow pipe, which is called as volcanic pipe. Volcanic materials of various sorts are ejected through this pipe and the vent situated at the top of the pipe. (Figure: 4)

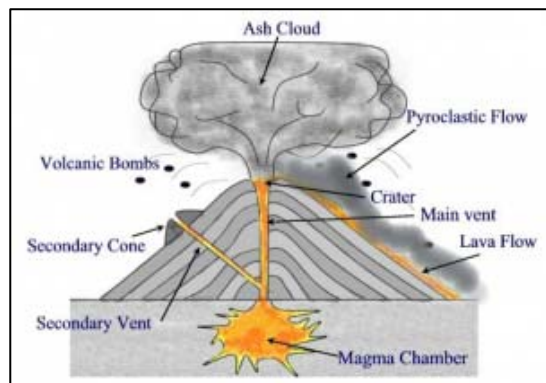


Figure 4: Main Features of a Volcano

3.4 Volcanic crater and caldera

The enlarged form of volcanic vent is known as volcanic crater and caldera. Volcanic materials include lavas, volcanic dust, ashes, fragmental materials etc.

4. Volcanic materials or material ejected from volcanoes

Volcanic materials discharged during eruption include gases and vapour, lavas, fragmental materials and ashes. (Figure: 5)

- Vapour and Gases
- Magma and Lava
- Fragmental or Pyroclastic material

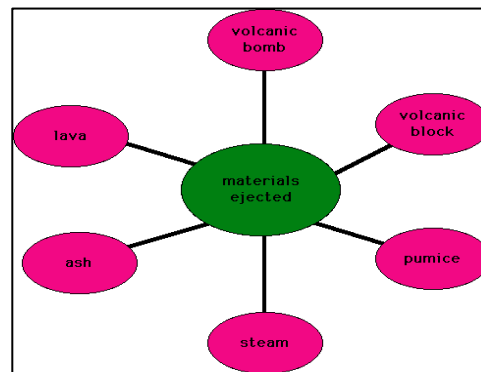


Figure 5: Material ejected from a Volcano

5. Causes of Volcanic Eruption

5.1 Origin of Magma

The main factor of volcanic eruption is magma in the below of the crustal surface. Magma is originated due to rocks molten which need to heat in the inner layers of the earth surface.

5.2 Primordial Heat

The earth in its origin is a fire ball which has become solid on upper part due to cold slowly. But today, there is presence primordial heat in it.

5.3 Plate Tectonics

Volcanic eruptions are very closely associated with plate boundaries. The types of plate movements and plate boundaries also determine the nature and intensity of volcanic eruptions. Most of the active fissure volcanoes are found along the mid-oceanic ridges which represent splitting zones of divergent plate boundaries. Two plates move in opposite directions from the mid-oceanic ridges due to thermal convective currents which are originated in the mantle below the crust (plates). This splitting and lateral spreading of plates creates fractures and faults (transform faults) which cause pressure release and lowering of melting point and thus materials of upper mantle lying below the mid-oceanic ridges are melted and move upward as magmas under the impact of enormous volume of accumulated gases and vapour. This rise of magmas along the mid-oceanic ridge causes fissure eruptions of volcanoes and there is constant upwelling of lavas. These lavas are cooled and solidified and are added to the trailing ends of divergent plate boundaries and thus there is constant creation of new basaltic crust. The volcanic eruptions of Iceland and the islands located along the mid-Atlantic ridge are caused because of sea-floor spreading and divergence of plates. (Figure: 6)

5.4 Origin of gases and vapour

Origin of gases and vapour due to heating of water which reaches underground through percolation of rain water and melt-water (water derived through the melting of ice and snow).

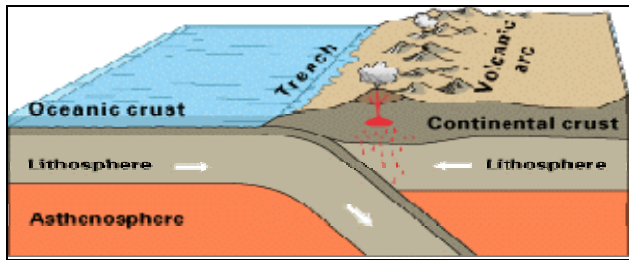


Figure 6: Oceanic-Continental Convergence

5.5 The ascent of magma forced by enormous volume of gases and vapour.

5.6 The occurrence of volcanic eruption either violent explosive central type or quiet fissure type depending upon the intensity of gases and vapour and the nature of crustal surface.

5.7 Earthquake.

5.8 Presence of weak land parts.

6. Types of Volcanoes

Volcanoes are classified on the basis of the mode of eruption and the period of eruption and the nature of their activities.

6.1 Classification on the basis of the nature of volcanic eruptions

Volcanic eruptions occur mostly in two ways. (1) Violent and explosive type of eruption of lavas, volcanic ashes and fragmental material through a narrow pipe and small opening under the impact of violent gases and (2) quiet type or fissure eruption along a long fracture or fissure or fault due to weak gases and huge volume of lavas. Thus, on the basis of the nature and intensity of eruptions volcanoes are divided into two types.

6.1.1 Volcanoes of central eruption type

Central eruption type or explosive of volcanoes occur through a central pipe and small opening by breaking and blowing of crustal surface due to violent and explosive gases accumulating deep within the earth. The eruption is so rapid and violent that huge quality of volcanic materials consisting of lavas, volcanic dusts, and volcanic ashes, fragmental materials etc. are ejected up to thousand of meters in the sky. These materials after falling down accumulate around the volcanic vent and form volcanic cones of various sorts. Such volcanoes are very destructive and are disastrous natural hazards. Explosive volcanoes are further divided into 5 sub types on the basis of difference in the intensity of eruption, variation in the ejected volcanic material.

- Hawaii type of volcanoes
- Strombolian type of volcanoes
- Vulcanian type of volcanoes
- Peleean type of volcanoes
- Visuvius type of volcanoes

6.1.2 Fissure eruption type of volcanoes

Such volcanoes occur along a long fracture, fault and fissure and there is slow upwelling of magma from surface. The speed of lava movement depends on the nature of magma, volume of magma, slope of ground surface and temperature conditions. The Lake fissure eruption of 1783 in Iceland was so quick and enormous that huge volume of lavas measuring about 15 cubic kilometers was poured out from a 28 km long fissure. The lava flow was so enormous that it travelled a distance of 350 kilometers.

6.2 Classification on the basis of periodicity of eruptions

Volcanoes are divided into 3 types on the basis of period of eruption:

- Active Volcanoes (Figure: 7)
- Dormant volcanoes
- Extinct volcanoes

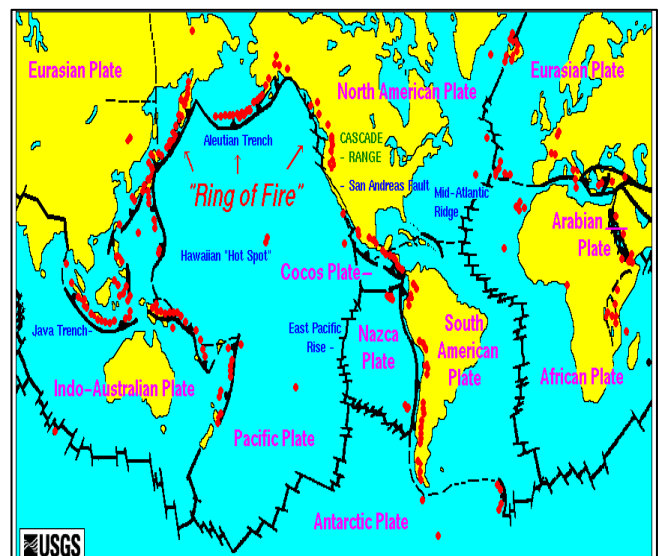


Figure 7: Active Volcanoes, Plate Tectonics and the "Ring of Fire"

7. Volcanic Landforms

7.1 Extrusive Volcanic Topography

7.1.1 From Explosive type of eruption

- Elevated Forms, e.g. volcanic cones
- Depressed Forms, e.g. crater and caldera

7.1.2 From Fissure eruptions

- Lava Plateaus and domes
- Lava Plains

7.2 Intrusive Volcanic Topography

8. World Distribution of Volcanoes

The spatial distribution of volcanoes over the globe is well marked and well understood because volcanoes are found in a well defined belt or zone. Volcanoes are associated with the weaker zone of the earth's crust. The weaker zones of the earth are represented by folded mountains (Western

cordillera of North America, Andes Mountains of East Asia and East Indies) with the exceptions of the Alps and the Himalayas, and the fault zones. More volcanic eruptions along costal margins and during wet season denote the fact that there is close relationship between water and volcanic eruptions. (Figure: 8). There are also three major belts or zones of volcanoes in the world.

- Circum- Pacific Belt
- Mid- Continental and Atlantic Belt
- Intra - Plate volcanoes



Figure 8: World Distribution: Major Volcanoes

9. Use of Remote Sensing and GIS in Volcanic Eruption

Volcanic eruption is a major problem in many countries. Remote Sensing and GIS is most important tools to support the decision-making process.

9.1 Monitoring of Volcanic Eruption

The institute of Geological and Nuclear science (GNS) monitors and assesses New Zealand’s volcanoes regularly and issue scientific alert. (Figure: 9) Scientists look for changes.

- The composition of gases produced by volcano
- The amount of gases being produced by volcano
- Water temperature
- Ground water level changes
- Topography (land feature)

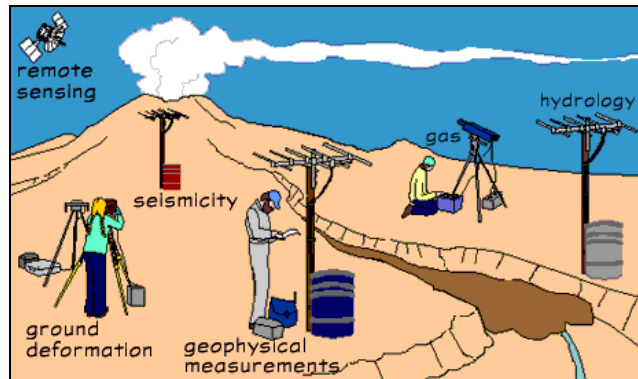


Figure 9: Types of Monitoring Techniques

9.2 How are Volcanoes Monitored?

Before an eruption happens, magma moves up towards the ground surface. (Figure: 10) Volcanologists use several methods to detect the movement of magma:

- Detecting earthquakes
- Measuring ground deformation
- Monitoring of volcanic gases
- Monitoring changes in the chemistry and temperature of greater lakes.



Figure 10: Volcanoes Monitored

The USGS Volcano Hazards Program monitors volcanoes for signs of unrest (activity). We analyze and interpret the data we collect from our networks of instruments. The data and an understanding of what the data have meant in the past are crucial for determining when a volcano might erupt. Most data can be accessed from our offices in the observatories but visits to the volcanoes, when possible, add valuable information.

When a volcano begins to show new or unusual signs of activity, the monitoring data help in answer critical questions necessary for assessing and then communicating timely information about volcanic hazards. For example, prior to the 2005 activity at Mount St. Helens monitoring equipment recorded a large increase in earthquake activity. Scientists quickly examined other monitoring data including gas, ground deformation, and satellite imagery to assess if a

magma or fluid was moving towards the surface. Based on the history of the volcano and the analysis of the monitoring data, the scientists were able to determine what types of materials could be moving towards the surface. The possible magma and fluid compositions helped figure out what types of hazards could potentially occur. The possible types of hazards help determine what real-time warnings are needed to prevent loss of life and property damage.

9.3 Monitoring of Ground Deformation

As the magma approaches the surface of the earth, and moves into the conduit below the vent of a volcano, the pushing aside of the surrounding rocks, to make way for the magma causes the ground surface to move and the volcano to swell. This rising or swelling can be detected by ground deformation surveys using leveling, triangulation and GPS survey. Geodetic measurements are used to monitor changes in the shape of the ground surface caused by the movement of magma towards the surface. Technique used by GNS include traditional triangulation and trilateration techniques which measure distances with electric distance measuring equipment (EDM), while ground tilting is measured by precise leveling and the use of the volcanic lakes on Raoul island, and at lakes Tarawera, and Taupo. At White Island a precise leveling network was established in 1966 on the floor of main crater to measure changes in crater height. Horizontal control surveys have been repeated across the Taupo Fault Belt, both north of Taupo and south of Rotorua, about the Octavia Volcanic centre using both traditional triangulation and trilateration techniques, and since 1991 GPS technologies. (Figure: 9)

9.4 Monitoring of the Chemistry of Volcanic Gases and Crater Lakes

Magma deep in the earth contains gases dissolved in it. As the magma rises to the shallow levels, these gases are released and, because they are so mobile when compared to the sluggish liquid magma, they rise to the surface and are discharged through gas vents as fumaroles. The temperature and absolute amounts of the gases and for the relative proportions of different gases give information on the state of the magma. Two scales of monitoring are required for active volcanoes. The first is background monitoring between crises using a limited number of fixed instruments or sampling point. The second scale is the monitoring during a crisis. This can require a much greater deployed of monitoring equipment and personnel, but only for a finite time. Changes in the volcanic gas chemistry, the rate of gas mission (for example SO₂) from Crater Lake and the thermal spring waters are used to detect changes in the behaviour of the volcanoes and their associated geothermal systems. Geochemical surveys include sampling of volcanic gases from selected fumaroles at places like White Island, Mount Tongariro, and the summit crater of Ngauruhoe.

GNS also has a correlation spectrometer which enables us to monitor the amount of SO₂ gas emitted from New Zealand's volcanoes. Changes in the ground water, lake levels, rate of stream flow and the temperatures of such waters often give evidence of unrest within a volcano. Other monitoring

includes measurements of the levels and temperature of Blue and Green Lake at Raoul Island, along with regular ground temperature measurements and water sampling.

9.5 Monitoring of Volcanic Earthquakes

Earthquake commonly provide the first indication of volcanic unrest. There are five volcanoes seismic in operation around New Zealand's volcanoes. Three are operated by GNS in the Taupo Volcanic zone. The volcano seismic networks at Taranaki and Auckland are operated by their regional councils. Raoul Island, New Zealand's most northern and one of the most active volcanoes, also has a seismograph on it. Volcanoes produce two types of seismic signature, the first are called 'volcanic earthquakes', the other is 'volcanic tremor'. When the rocks are broken by the magma moving through them small earthquakes occur, 'volcanic earthquakes'. If the rocks are relatively cool and brittle the earthquake will be off a higher frequency those that break hot- softer rocks. When the hot volcanic gases that come from the magma pass through cracks on the way to the surface they cause a small ground vibration, this is called volcanic tremor. Volcanic tremor can also be caused by the movement of molten magma.

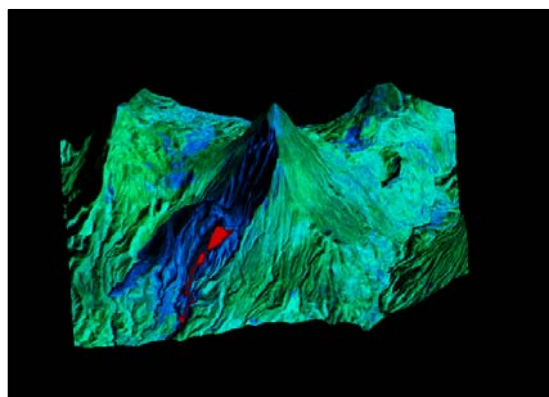


Figure 11: False color thematic mapper image of Santa Maria with thermal infrared (band 6) in red. The image is wrapped on digital topography, for an artificial three dimensional rendition.

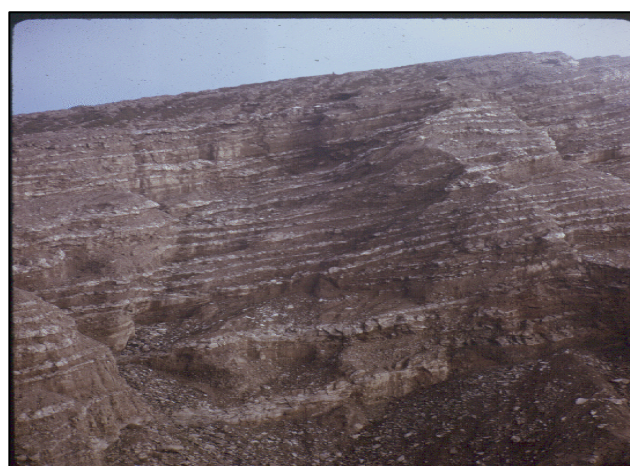


Figure 12: Aerial photograph of interior explosion in 1902, View from the slope, Light coloured layers are flow interiors, darker materials fragmental rocks

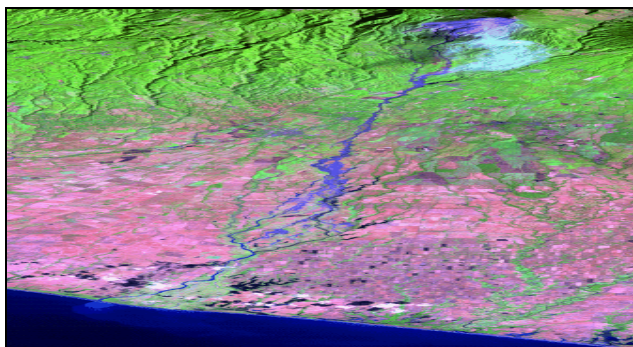


Figure 13: Landsat Thematic Mapped Image

9.6 Mitigation Plan

The mitigation plan goals and action items are derived from review of regional and national hazards mitigation plans and planning literature, guidance from the Washington County Natural Hazards Mitigation Plan Steering Committee, and interviews with Washington County stakeholders. The goals for the Washington County Natural Hazards Mitigation Action Plan are broad based to include all of the identified hazards addressed in the plan. Goals for this mitigation plan addressed four categories:

- Life, Property and Natural Systems
- Public Awareness and Partnerships
- Emergency Services and Implementation

9.6.1 Volcanic eruption mitigation action items

The volcanic eruption mitigation action items provide direction on specific activities that cities, organizations, and residents in Washington County can undertake to reduce risk and prevent loss from volcanic eruption events. There are three short and two long term volcano hazard action items described. Each action item is followed by ideas for implementations, which can be used by the steering committee and local decision makers in pursuing strategies for implementation.

10. Case Study (Mount St. Helens Montana, USA, 1980, May 18)

Mount St. Helens had been dormant for 123 years when it suddenly erupted at 8:32 a.m. Ash-filled steam and gas blasted out horizontally from the mountain at up to 670 miles per hour, snapping off six million trees and scattering them like toothpicks over a 130,000-acre area. The event occurred in near silence. Muted by the ash, dust, and fir needles in the air, the sound waves only carried thirty feet. The explosion of the volcano was as large as 500 small atomic bombs, but luckily there were very few deaths. The death toll was 34, with 27 others missing. 10,000 animals are estimated to have been killed, along with 15,000 acres of destroyed forestland. Damage was estimated to exceed \$800 million. (Figure: 14)

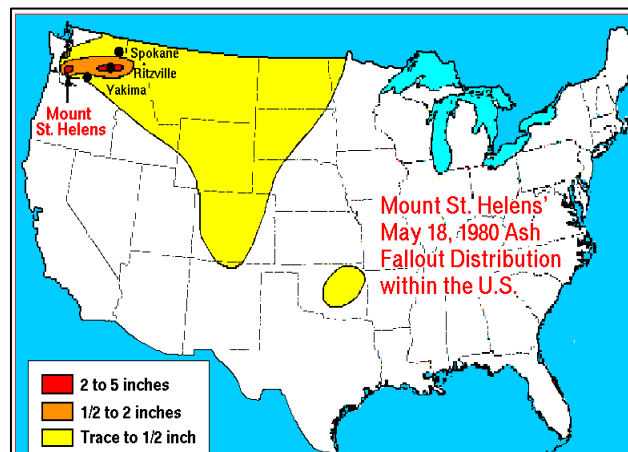


Figure 14: Mount St. Helens Montana, USA, 1980, May 18

11. Conclusion

Volcanic eruption is a major problem in many countries. Remote Sensing and GIS is most important tools to support the decision making process. Volcanic eruption can lead to a diversity process such as explosion, pyroclastic flow, lahars, lava flows and ashfall for the mapping of volcanic landforms and deposits. The convention interpretation of stereo aerial photograph is most used technique. (Figure: 12) The stereo image does not only give a good view of the different lithologies and the geomorphologic characteristics of the volcanic terrain, but it can also be used for a delineating possible paths of different kinds of lava flows. Remote sensing is the ability of the visible and infrared radiation to discriminate between fresh rock and vegetated surfaces. This is useful because vegetation quickly develops on all areas except those disturbed by the volcano or other causes.

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Author Profile



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