UNIT 3 SPECTRAL SIGNATURE

Structure

3.1 INTRODUCTION

In the previous two units, you have studied about electromagnetic radiation (EMR) and its interaction with the Earth's surface and its atmosphere. You have also learned about the refraction, reflection, scattering, absorption, and transmission of EMR. Different Earth's features display different spectral behaviour depending upon their interactions with EMR. This spectral behaviour forms the basis on which Earth features on the image are identified by an image analyst. In this unit, we will discuss about the spectral properties and signatures of the common Earth's surface materials such as vegetation, water, soil, minerals and rocks.

Objectives

After studying this unit, you should be able to:

- define spectral signature;
- explain how spectral signatures differ with object to object;
- distinguish the objects such as vegetation, water, soil, minerals and rocks based on their spectral signatures; and
- identify and explain spectral signatures by reading graphs.

3.2 WHAT IS SPECTRAL SIGNATURE?

Spectral signatures are the combination of reflected, absorbed and transmitted or emitted EMR by objects at varying wavelengths, which can uniquely identify an object. When the amount of EMR (usually intensity of reflected radiation or reflectance in percentage) coming from the material is plotted over a range of wavelengths, the connected points produce a curve which is known as ***spectral signature*** of the material or in other words spectral response curve. To interpret remote sensing images, it is absolutely important to start with a basic understanding of spectral signature, which means how different terrain features such as water, rock, soils, and vegetation, interact with the different wavelengths (bands) of the EMR.

The spectral signature of an object is a function of the incident EMR and that part of electromagnetic (EM) spectrum in which they are interacting. The energy reflected back from the object is measured by instruments such as task-specific spectrometer.

All spectral reflectance data are unique to the material and the environment in which they are measured as shown in Fig. 3.1. Mineral/rock signatures, for example, will vary from sample to sample. Vegetation is even more variable, being dependent on growth stage, plant health, and moisture content.

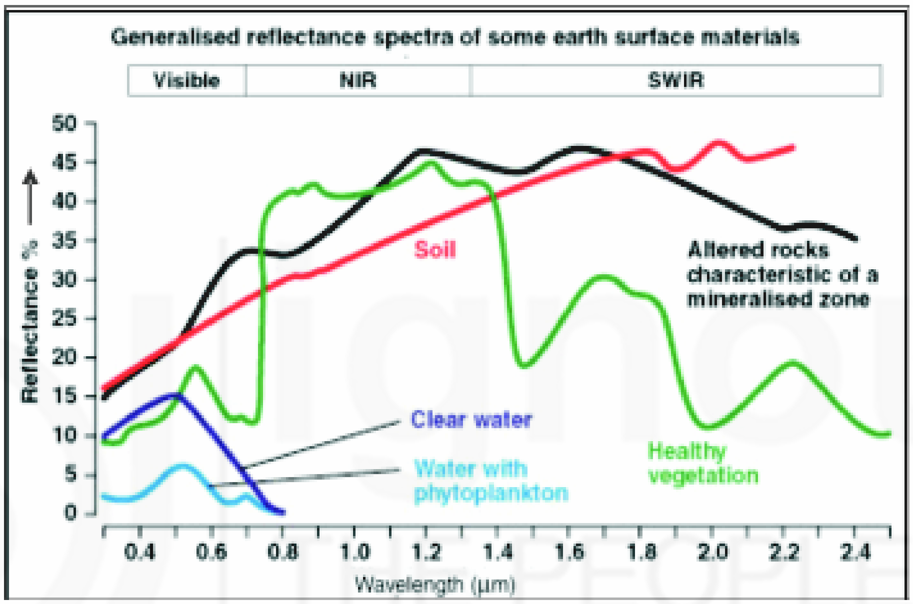


Fig. 3.1: Spectral signatures of common Earth materials in NIR – near infrared, SWIR – shortwave infrared regions of the electromagnetic energy (modified after www.rsacl.co.uk/rs.html)

Let us now study spectral properties of common Earth's surface materials individually.

3.3 SPECTRAL SIGNATURE OF VEGETATION

As you see, vegetation appears green. We know that an object appears green when it reflects green light (light in green region within the visible range of the EM spectrum). In case of vegetation, reflection of green light is due to the presence of the chlorophyll pigment in plant leaves. Presence of the chlorophyll pigment results in unique spectral signature of vegetation that enables us to distinguish it easily from other types of land cover (non-living) features in an optical/near-infrared image. The reflectance of vegetation is low in both the blue and red regions of the EM spectrum, due to absorption of blue and red wavelengths by chlorophyll for photosynthesis. It has a peak reflectance at the green region that gives green colour to vegetation. In the near infrared (NIR) region, the reflectance is much higher than that in the visible band due to the cellular structure in the leaves. Hence, vegetation can be easily identified in the NIR region of spectrum. Typical spectral signature of green vegetation is shown in Fig. 3.2.

Reflectance of vegetation changes according to the composition, maturity and health of vegetation. The amount of chlorophyll content determines the health of vegetation. Chlorophyll strongly absorbs radiation in the red and blue wavelengths but reflects green wavelengths. Leaves appear 'greenest' to us when chlorophyll content is at its maximum. In certain seasons, there is less chlorophyll in the leaves; so, there is less absorption and proportionately more reflection of the red wavelengths, making the leaves appear red or yellow (yellow is a combination of red and green wavelengths).

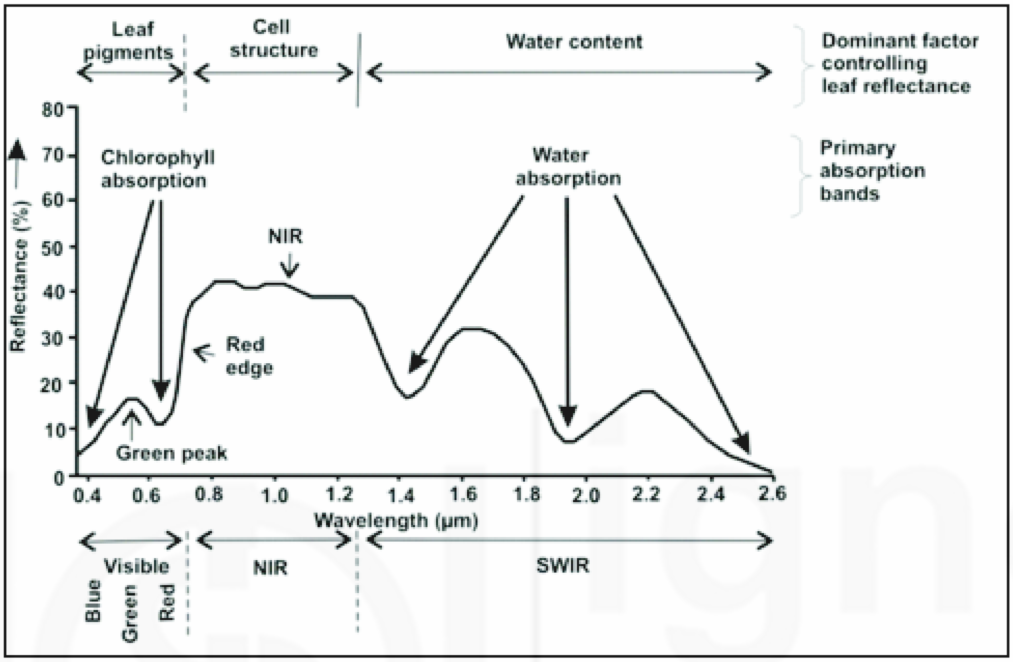


Fig. 3.2: Typical spectral signature of green vegetation (source: Hoffer, R.M., 1978)

The internal structure of healthy leaves acts as excellent diffuse reflectors of near-infrared wavelengths. If our eyes were sensitive to near infrared, trees would appear extremely bright to us at these wavelengths. In fact, measuring and monitoring the NIR reflectance is one of the ways by which scientists can determine how healthy (or unhealthy) the vegetation is. Spectral signatures of healthy, stressed and severely stressed vegetation are shown in Fig. 3.3.

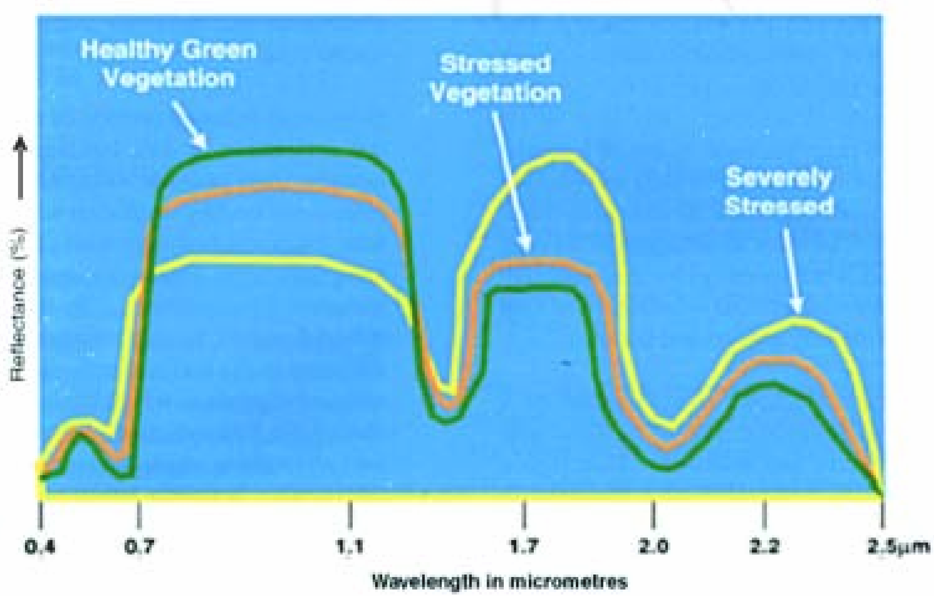
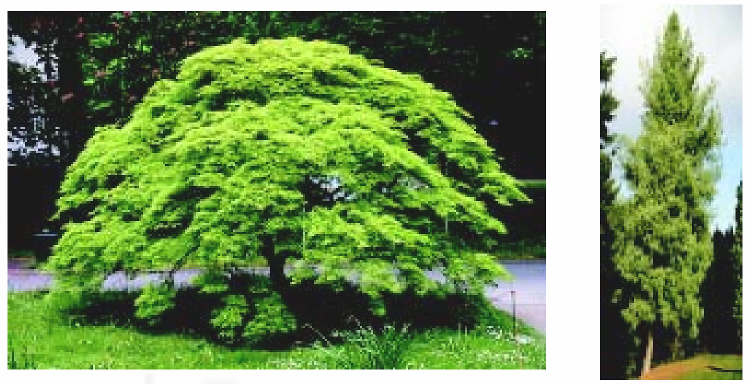


Fig. 3.3: Example of spectral signatures of healthy, stressed and severely stressed vegetations (source: http://rst.gsfc.nasa.gov/Sect3/Sect3_1.html)

The shape of the reflectance spectrum varies with the type of vegetation. For example, the reflectance spectra of deciduous and coniferous tress can be distinguished based on their reflectance spectrum. Deciduous trees (Fig. 3.4a) and coniferous trees (Fig. 3.4b) have almost similar reflectance in the visible region, but they vary in the NIR region, where deciduous trees have higher reflectance than coniferous tresses (Fig. 3.5). The reflectance spectrum also depends on other factors such as the leaf moisture content, physical, chemical characteristics and health of the plants.



(a) (b)

Fig. 3.4: (a) Deciduous tree - Maple; (b) Coniferous tree – Pine (source: http://theindoorbonsaitree.com)

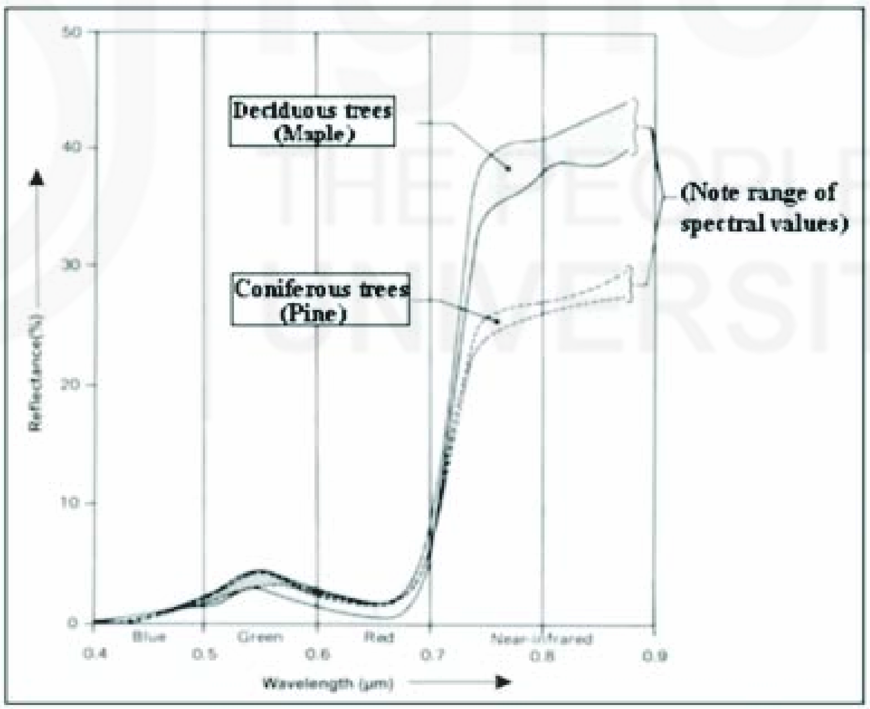


Fig. 3.5: Generalised spectral reflectance envelopes for deciduous (broad-leaved) and coniferous (needle-bearing) trees. Each tree type has a range of values at any wavelength (source: Lillesand et. al, 2007)

The reflectance of vegetation in the shortwave infrared (SWIR) region (e.g., band 5 of Landsat Thematic Mapper (TM) and band 4 of SPOT- 4 sensors) is more varied, depending on the types of plants and the plant's water content (Fig. 3.6). Water has strong absorption bands around 1.45, 1.95 and 2.50 µm. Outside these absorption bands in the SWIR region, reflectance of leaves generally increases when leaf liquid water content decreases. This property can be used for identifying tree types and plant conditions from remote sensing images. The SWIR band can be used in detecting plant drought stress and delineating burnt areas and fire-affected vegetation. The SWIR band is also sensitive to the thermal radiation emitted by intense fires, and hence can be used to detect active fires, especially during night-time when the background interference from SWIR in reflected sunlight is absent.

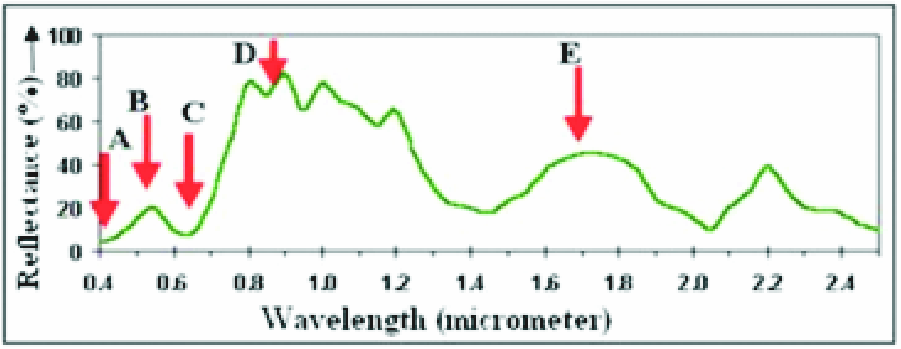


Fig. 3.6: Typical satellite image reflectance spectrum of vegetation. Note: The labelled arrows indicate the common wavelength bands used in optical remote sensing of vegetation: A- blue band, B - green band; C - red band; D - near IR band; E - shortwave IR band (modified after www.crisp.nus.edu.sg/~research / tutorial/optical.htm).

Spectral Characteristics of Vegetation

The spectral reflectance of vegetation can be detected in the following three major regions of EM spectrum:

- **Visible region** (400-700 nm): Low reflectance, high absorption, and minimum transmittance. The fundamental control of energy-matter interactions with vegetation in this part of the spectrum is plant pigmentation.
- **NIR** (700-1350 nm): High reflectance and transmittance, very low absorption. The physical control is internal leaf structures.
- **Middle Infrared (MIR)** (1350-2500 nm): As wavelength increases, both reflectance and transmittance generally decrease from medium to low, while absorption increases from low to high. The primary physical control in these middle-infrared wavelengths for vegetation is *in vivo* water content. Figs. 3.7 and 3.8 show spectral reflectance characteristics of vegetation in different conditions.

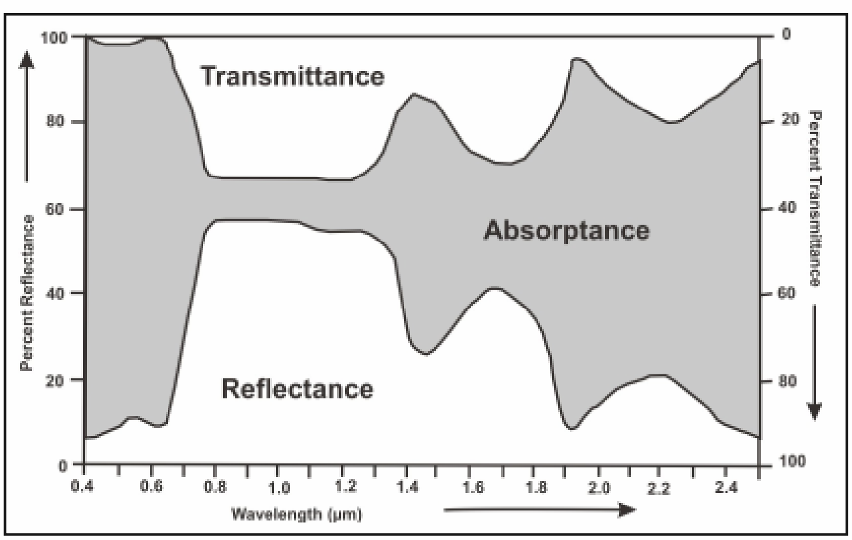


Fig. 3.7: Partitioning of vegetation spectral reflectance in the visible, NIR and MIR regions of the EM spectrum (modified after www.cps-amu.org/sf/notes/m1r-1-8.htm)

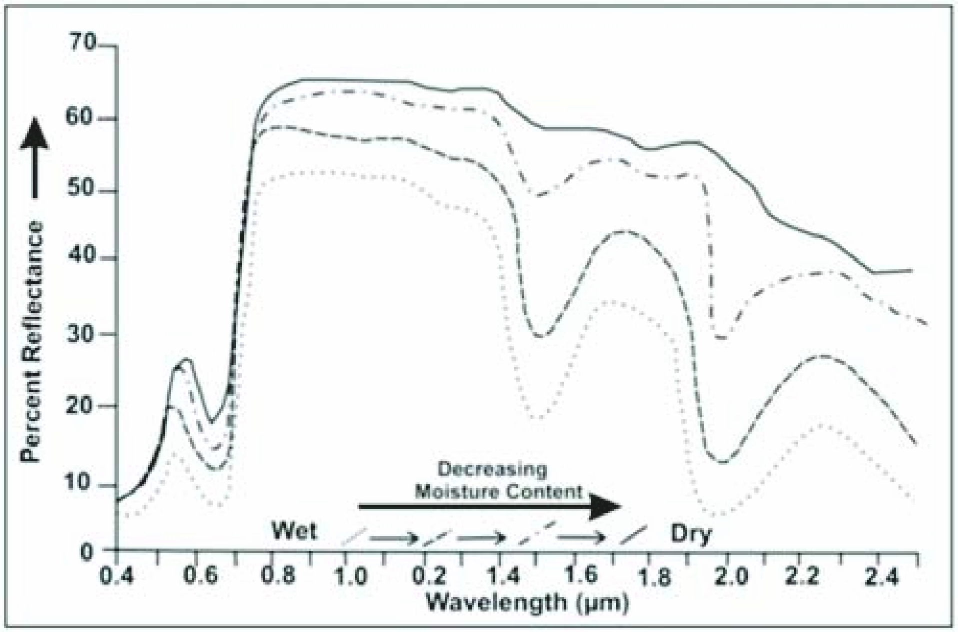


Fig. 3.8: Variation in the spectral reflectance characteristics of vegetation according to leaf moisture content (modified after www.cps-amu.org/sf/notes/m1r-1-8.htm)

3.4 SPECTRAL SIGNATURE OF SOIL

In general, soil surfaces appear brown to the human eyes. Brown colouring is a product of green and red EMR such that 'brown' surfaces absorb more blue wavelength than either green or red. Furthermore, very little energy is transmitted through soil; the majority of the incident flux is absorbed or reflected. The technical term for these types of surface is single scatterer. In the case of soil surfaces, the level of reflectance gradually increases with wavelength in the visible and NIR spectral regions. You can see from Fig. 3.9 that maximum soil reflectance occurs at NIR wavelength.

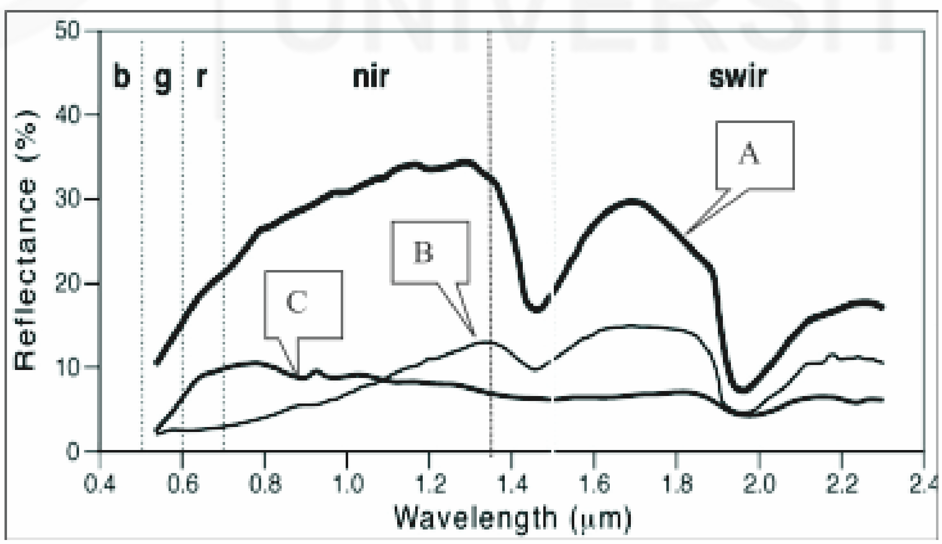


Fig. 3.9: Reflectance of bare soil surfaces. A) minimally altered , B) organic dominated and C) iron dominated (modified after Stoner and Baumgardner, 1981)

As water is relatively strong absorber of all wavelengths, particularly those longer than the red part of the visible spectrum. Therefore, as the moisture content of the soil increases, the overall reflectance of that soil tends to decrease. Soil rich in iron oxide reflects proportionally more of the red than other visible wavelengths and therefore appears red (rust colour) to the human eyes. A sandy soil, on the other hand, tends to appear bright white in imagery because visible wavelengths are more or less equally reflected; when slightly less blue wavelengths are reflected, it results in a yellow colour.

According to Stoner and Baumgardner (1981), following are the four most important characteristics of a soil that determine its reflectance properties:

- moisture content
- organic matter content
- texture and structure
- iron oxide content

We will now discuss here how the above factors determine soil properties.

Soil Moisture Content

The presence of soil moisture reduces the surface reflectance of soil at all visible wavelengths (Jensen, 1983). This occurs until the soil is saturated, at which point further additions of moisture have no effect on reflectance.

Reflectance at NIR wavelengths is also negatively related to soil moisture; an increase in soil moisture will result in a particularly rapid decrease in reflectance due to water (H_2O) and hydroxyl (OH) absorption features at 0.9 ìm, 1.4 ìm, 1.9 ìm, 2.2 ìm and 2.7 ìm. The effect of water and hydroxyl absorption is more noticeable in clay soils because they have much bound water and very strong hydroxyl absorption properties (Fig. 3.10).

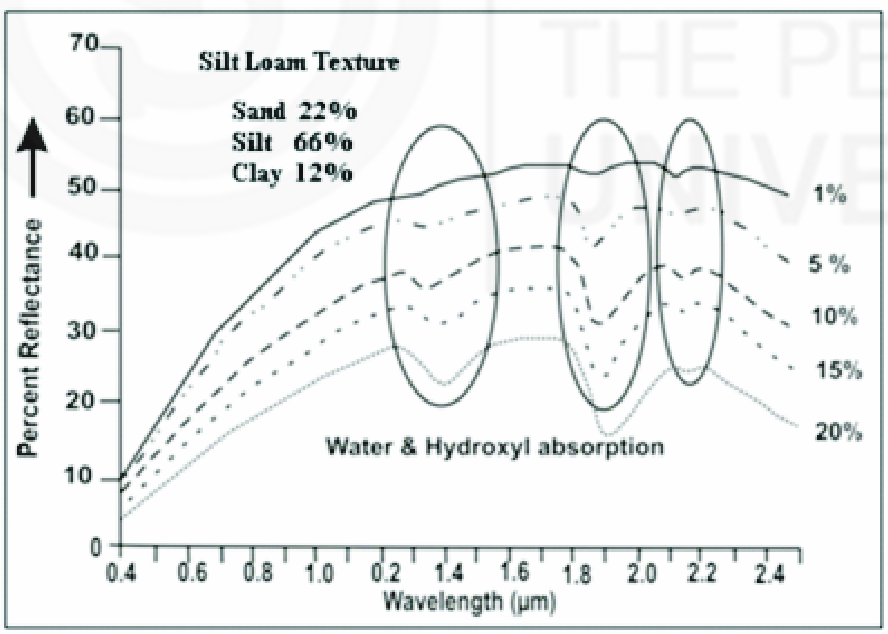


Fig. 3.10: Variation in the spectral reflectance characteristics of soil according to moisture content (modified after www.cps-amu.org/sf/notes/m1r-1-8.htm)

Organic Matter Content

The organic matter of soil is dark in colour and its presence will decrease the reflectance from the soil up to an organic matter content of around 4-5%. When the organic matter content of the soil is greater than 5%, the soil appears black and any further increase in the organic matter will have little effect on reflectance (Curran, 1985).

Texture and Structure

Texture (the proportion of sand, silt and clay particles) is related to structure(arrangement of sand, silt and clay particles into aggregates) and, therefore, they will be discussed together. The relationship between texture and structure can best be described by reference to following two contrasting soil types (Fig. 3.11):

- a **clay soil** tends to have a strong structure, which leads to a rough surface on ploughing, causing small shadows and lowering reflectance values.
- in contrast, a **sandy soil** exhibits weak structure, which leads to a fairly smooth surface on ploughing with few shadows. It should be noted that the effects of soil structure complement other properties such as low moisture and organic matter content to increase the level of sandy soil reflectance.

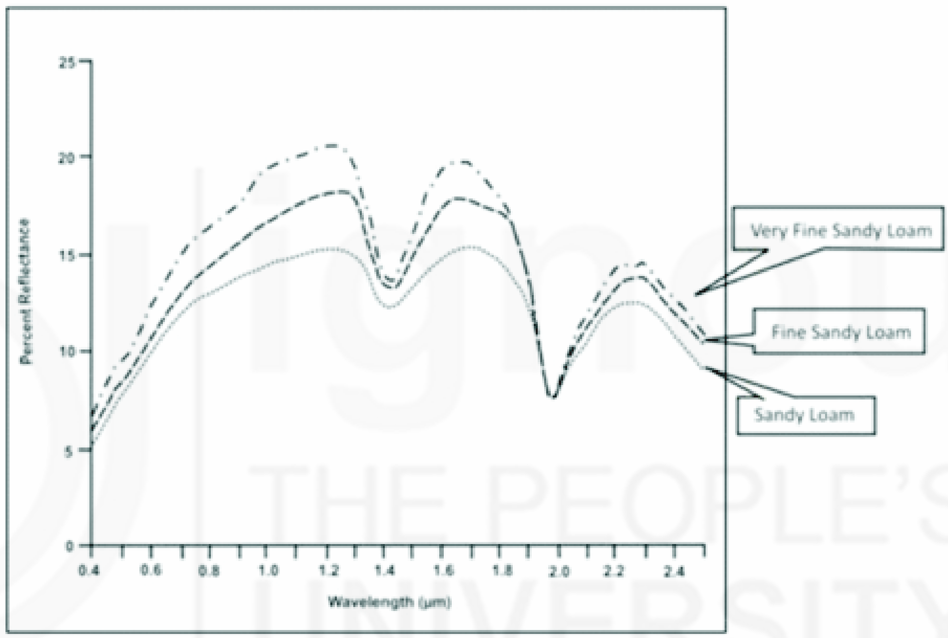


Fig. 3.11: Variation in the spectral reflectance characteristics of soil according to soil texture (modified after www.cps-amu.org/sf/notes/m1r-1-8.htm)

Iron Oxide Content

Iron oxide gives rusty red colouration to many soils by coating or staining individual soil particles. Iron oxide selectively reflects red light (0.6 - 0.7 ìm) and absorbs green light (0.5 - 0.6 ìm). This effect is so pronounced that Vincent (1973) used a ratio of red to green reflectance to locate iron ore deposits (Curran, 1985).

Spend 5 mins

Check Your Progress I

1) Now its time to undertake some experimental work. Pour yourself a glass of water and go outside. Pick up a handful of soil and observe the colour. It is preferable that the soil is not too organic-rich because that will make it difficult to see any changes in colour. Wet the soil a little at a time and observe any change in colour.

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3.5 SPECTRAL SIGNATURE OF WATER

Unlike soil, the majority of the radiant flux incident upon water is not reflectedbut is either absorbed or transmitted. At visible wavelengths of EMR, verylittle energy is absorbed, a small amount usually under 5% is reflected andthe majority is transmitted. If you happen to be standing in water you can see your foot/toes through the water. Water absorbs strongly at NIR wavelengths, leaving little radiation to be either reflected or transmitted (Fig. 3.12).

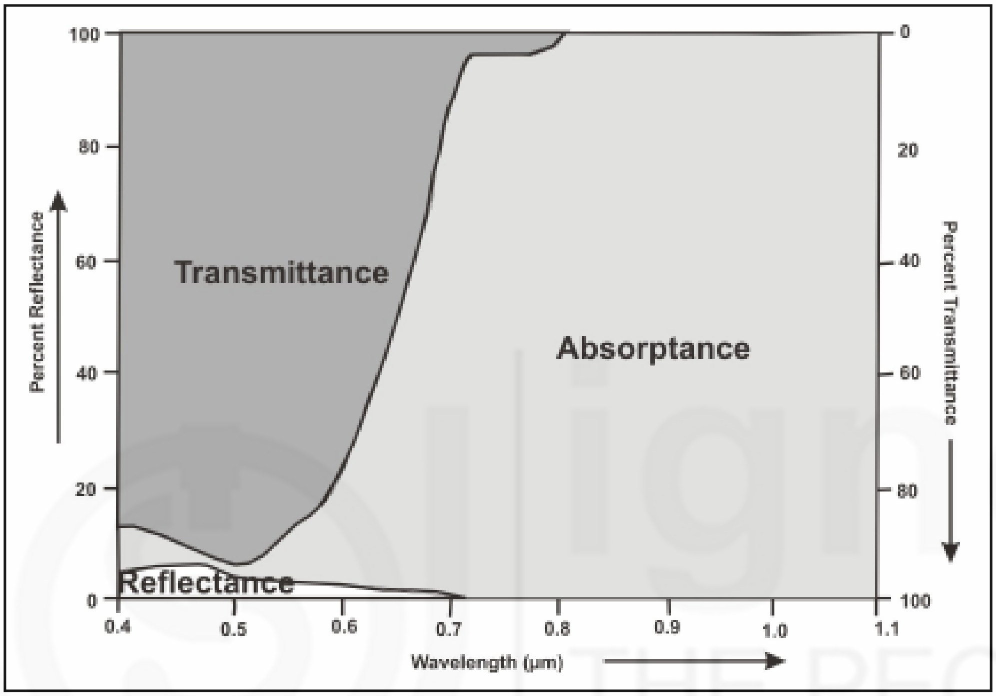


Fig. 3.12: Spectral reflectance characteristics of deep, clear water (modified after www.cps-amu.org/sf/notes/m1r-1-8.htm)

Although water surfaces may be more homogeneous than soil surfaces, you can still expect some variability in the reflectance of a body of water. The following two most important factors are:

- depth of the water
- materials within the water

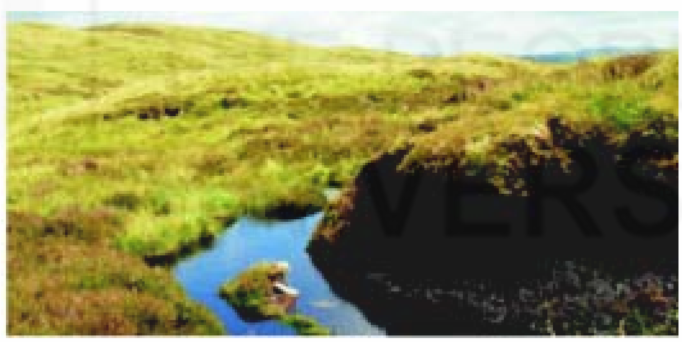
In shallow water, some of the radiation is reflected not by the water itself but from the bottom of the water body. Therefore, in shallow pools and streams, it is often the underlying material that determines the water body's reflectance properties.

Longer wavelengths of visible and NIR regions of EMR absorb more by water than shorter visible wavelengths. Thus water typically looks blue or blue-green due to stronger reflectance at these shorter wavelengths, and darker if viewed at red or NIR wavelengths. If there is suspended sediment present in the upper layers of the water body, then this will allow better reflectivity and a brighter appearance of the water.

The apparent colour of the water will show a slight shift to longer wavelengths. Suspended sediment can be easily confused with shallow (but clear) water, since these two phenomena appear very similar. Chlorophyll in algae absorbs more of the blue wavelengths and reflects the green, making the water appear greener in colour in the presence of algae. The topography of the water surface (rough, smooth, floating materials, etc.) can also lead to complications for water-related interpretation due to potential problems of specular reflection and other influences on colour and brightness.

The three most common materials suspended in water are non-organic sediments, tannin and chlorophyll/phytoplankton:

- non-organic silts and clays increase the reflectance at visible wavelengths due to interaction with and scattering by soil-like particles (Fig. 3.9). If you are lucky enough to have visited a glacier, then you may recall the milky white colouration of a proglacial stream. This is caused by the high concentration of fine rock flour sediment suspended in the water.
- in agricultural scenes, the main colouring agent is tannin produced by decomposing humus. This is yellowish to brown in colour and results in decreased blue and increased red reflectance. A good example of the effects of tannin can be found in streams that drain peat moorlands.
- chlorophyll content must be high before changes in reflectance can be detected (Piech et. al, 1978). Waterbodies that contain excessive levels of chlorophyll have reflectance properties that resemble, at least in part, those of vegetation with increased green and decreased blue and red reflectance.



Drainage/waterbody in peat moorlands (source: http://planetearth.nerc.ac.uk.features/story.aspx?id=446).

High Chlorophyll content of water body

Fig. 3.13: Photographs of water bodies with different water content

3.6 SPECTRAL SIGNATURE OF MINERALS AND ROCKS

Rocks, like soils, are single scatterer and exhibit relatively simple spectral properties. Unlike soils, rock reflectance is less dependent on water content and completely independent of organic matter content, texture or structure. Rock spectral reflectance primarily depends on their mineral composition. Mineral reflectances measured in the laboratory (Fig. 3.14) show following two sources of variation:

- the overall level of reflectance
- specific absorption features

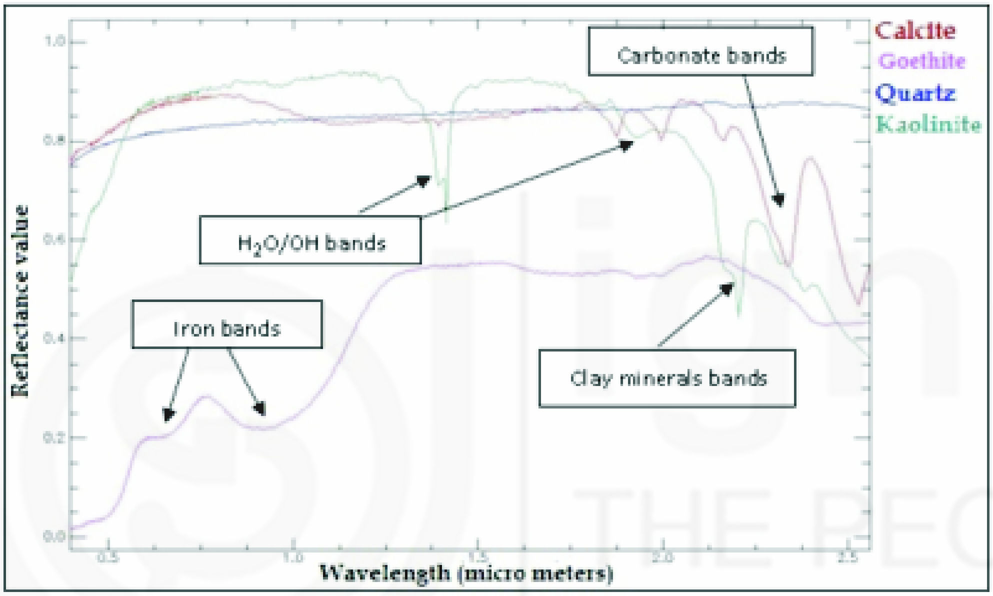


Fig. 3.14: Reflectance of selected minerals

Low reflecting minerals such as goethite (an ore of iron) have spectral properties similar to soil surfaces - low to moderate reflectance at visible wavelengths increasing into the NIR.

High reflecting minerals, such as quartz (silicate mineral) and calcite (calcium carbonate), exhibit almost uniformly high reflectance throughout the visible, NIR and SWIR spectrum. Differences between high reflectance minerals occur at specific wavelengths and these absorption features are known as ***diagnostic absorption features***.

See, for example, the effect of carbonate on the reflectance of calcite at 2.35ìm. Some of the most pronounced absorption features are associated with clay minerals. As clays such as kaolinite (aluminum hydroxide silicate) may be associated with the presence of precious metals, it was not surprising that the mineral exploration community were the drivers behind the decision to include a SWIR waveband on the Landsat TM sensor that measured reflectance at 2.08 – 2.35 ìm. They are now leading the way in hyper-spectral remote sensing at these wavelengths. Unlike other minerals, the strength of bonding between clay particles and water produces some absorption features at 1.4 ìm and 1.9 ìm. Photographs of a few minerals are shown in Fig. 3.15 as an example.

Fig. 3.15: Photographs of four different type of minerals

To find out more about the measurement and analysis of the rocks/mineral spectral signature in detail, you need to understand about the spectroscopy and hyper-spectral remote sensing. Kindly visit the US Geological Survey Spectroscopy Laboratory web site (http://speclab.cr.usgs.gov/) for details of reflection and absorption properties of various materials (spectra).

Finally, before summarising this section, it is important to draw your attention to the information regarding the description of the spectral properties and signatures of vegetation, soil, rocks/minerals and water surfaces which are typical of mid-latitude temperate climates. Those of you living or working in other parts of the world may experience a different set of surfaces or different canopy types. For example, in arid and semi-arid regions, you will find land surface with low vegetation cover, plenty of rock outcrops and soil cover with green land surface rather than soil, exhibit particular spectral characteristics with its mineral content. At high latitudes, you may observe snow or ice cover surfaces with exceptionally high reflectance. You must also be aware that solar elevation is generally low and therefore, objects cast longer shadows at high latitudes.

3.7 SUMMARY

Let us now summarise what you have learnt in this unit:

- Spectral signatures are the specific combination of reflected, absorbed and transmitted or emitted EMR at varying wavelengths, which can uniquely identify an object.
- Vegetation has a unique spectral signature that enables it to be distinguished easily from other types of Earth surface features in an optical/near-infrared image. Vegetation can be easily identified in the NIR region of EM spectrum.
- The shape of the vegetation reflectance spectrum varies with vegetation types, leaf moisture content, physical, chemical characteristics and health condition of the plants.

- Soil reflectance is high in NIR and SWIR regions of the EM spectrum. These signatures differ based on moisture, organic matter, texture, structure, and iron oxide content of soil.
- Water has higher reflectance in visible region of the EM spectrum. Longer wavelengths of the visible and NIR regions of EMR are absorbed more by water than shorter visible wavelengths. Thus, water typically looks blue or blue-green.
- Rock/minerals reflectances are completely independent of organic matter content, texture or structure. Rock spectral reflectance primarily depends on their mineral composition.
- Low reflecting minerals, such as geothite, have similar spectral properties to soil surfaces.
- High reflecting minerals, such as quartz and calcite, exhibit almost uniformly high reflectance throughout the visible, NIR and SWIR regions of the EM spectrum.
- Spectroscopy and hyper-spectral remote sensing technology are used for better understanding of spectral signature of specific materials.

3.8 UNIT END QUESTIONS

Spend 30 mins

1) What is spectral signature and why is it important?
2) Explain at which wavelengths does the dry soil differ from the moist soil?
3) Give reason why does a water body absorb most of the EMR?

3.9 REFERENCES

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- http://planetearth.nerc.ac.uk/features/story.aspx?id=446
- http://rst.gsfc.nasa.gov/Sect3/Sect3_1.html
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- Piech, K. R., J. R. Schott, and K. M. Stewart, (1978), The Blue-to-Green. Reflectance Ratio and Lake Water Quality. Photogrammetric Eng., 11, 1752-1688p.

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- Vincent, R.K., (1973), Ratio Maps of Iron Ore Deposits, Atlantic City District, Wyoming, Symposium on Significant Results obtained from the Earth Resources Technology Satellite-1, 1, 379-386p.

- www.cps-amu.org/sf/notes/m1r-1-8.htm
- www.crisp.nus.edu.sg/~research /tutorial/optical.htm
- www.rsacl.co.uk/rs.html

All the websites were retrieved between 1and10 May, 2011.

3.10 FURTHER/SUGGESTED READING

- Jensen, J.R. (2007), Remote Sensing of the Environment, Prentice Hall, 544p.
- Sabins, F.F. (1996), Remote Sensing, Principles and Interpretation, W H Freeman and Company, 450p.

3.11 ANSWERS

Check Your Progress I

1) You should have found that the presence of soil moisture reduces the surface reflectance of soil at all visible wavelengths. This occurs until the soil is saturated, at which point, further additions of moisture have no effect on reflectance.

Unit End Questions

1) Spectral signatures are the specific combination of reflected, absorbed and transmitted or emitted EMR by objects at varying wavelengths, which can uniquely identify an object. It is important because this forms the basis of image interpretation.

2) Dry soil differs from moist soil at 0.9 ìm, 1.4 ìm, 1.9 ìm, 2.2 ìm and 2.7ìm wavelengths. An increase in soil moisture results rapid decrease in reflectance due to absorption of radiation at these wavelengths by water and hydroxyl ion.

3) The majority of the radiant flux incident upon water is not reflected;it is either absorbed or transmitted. At visible wavelengths of EMR, a small amount of energy is absorbed, about 5% is reflected andthe majority is transmitted. Water absorbs near infrared wavelengths strongly leaving little radiation to be either reflected or transmitted.

GLOSSARY

Absorption: A measure of the ability of a material to absorb electromagnetic radiation.

Active Remote Sensing: Remote sensing methods that provide their own source of electromagnetic radiation to illuminate any object. Radar is one example.

Atmospheric windows: The wavelength band at which electromagnetic radiation from space can penetrate the Earth's atmosphere.

Attenuation: The process by which radiation is reduced in intensity when passing through a medium. It is the combination of absorption and scattering processes.

Band: A wavelength interval in the electromagnetic spectrum. For example, in Landsat images the bands designate specific wavelength intervals at which images are acquired.

Blackbody: An ideal substance that absorbs the entire radiant energy incident on it and emits radiant energy at the maximum possible rate per unit area at each wavelength for any given temperature. No actual substance is a true blackbody, although some substances, such as lampblack, approach its properties.

Electromagnetic radiation: Energy propagated in the form of an advancing interaction between electric and magnetic fields. All electromagnetic radiation moves at the speed of light.

Electromagnetic spectrum: Continuous sequence of electromagnetic energy arranged according to wavelength or frequency.

Frequency: The number of wave oscillations per unit time or the number of wavelengths that pass a point per unit time.

Incidence angle: In radar, the angle formed between an imaginary line normal to the surface and another connecting the antenna and the target.

Infrared Radiation: Radiation emitted by the Earth's surface, the atmosphere and the clouds. It is also known as terrestrial or long-wave radiation.

IR: Infrared region of the electromagnetic spectrum that includes wavelengths from 0.7m to 1 mm.

Landsat: A series of remote sensing satellites in sun-synchronous polar orbit first launched in 1972 by USA. The Landsat satellites are the platforms for the multi-spectral scanner, return beam vidicons and thematic mapper.

Microwave: Region of the electromagnetic spectrum in the wavelength range of 0.1 to 30 cm.

Mie Scattering: When the particles in the atmosphere are the same size as the incident wavelength, Mie scattering takes place. Dust, pollen, smoke and water vapour in Earth's atmosphere are common causes of Mie scattering which tends to affect longer wavelengths.

Mineral: A natural substance having definite chemical composition and atomic structure and formed by inorganic process. Examples of mineral are calcite, quartz, mica.

Near Infrared (NIR): The shorter wavelength range of the infrared region of the EM spectrum, from 0.7 to 2.5 µm. It is often divided into very-near infrared (VNIR) covering the range accessible to photographic emulsions (0.7 to 1.0 µm), and the short-wavelength infrared (SWIR) covering the remainder of the atmospheric window from 1.0 to 2.5 µm.

Passive Remote Sensing: Remote sensing of energy naturally reflected or radiated from any object.

Photon: Minimum discrete quantity of radiant energy.

Planck's Law: An expression for the variation of emittance of a blackbody at a particular temperature as a function of wavelength.

Polarization: The direction of orientation in which the electrical field vector of electromagnetic radiation vibrates.

Quantum: The elementary quantity of EM energy that is transmitted in a particular wavelength. According to the quantum theory, EM radiation is emitted, transmitted, and absorbed as numbers of quanta, the energy of each quantum being a simple function of the frequency of the radiation.

Radar: Acronym for Radio Detection And Ranging. Radar is an active form of remote sensing instrument that operates in the microwave and radio wavelength regions

Radiometer: Device for quantitatively measuring radiant energy, especially thermal radiation.

Rayleigh scattering: The scattering of electromagnetic radiation by particles with dimensions much smaller than the wavelength of the radiation. In it the intensity of scattered radiation is inversely proportional to the fourth power of the incident wavelength.

Reflection: It is the process by which a surface of discontinuity turns back a portion of the incident radiation into the medium through which the radiation approached.

Refraction: It is the deviation of electromagnetic wave from a straight line as it passes through the atmosphere due to the variation of refractive index in the medium.

Rock: A natural aggregate of grains of one or more than one minerals. Examples of rocks are granite, basalt, marble, sandstone.

Satellite: An object in orbit around a celestial body.

Scattering: The phenomenon in which electromagnetic properties of the medium are responsible in deflecting the radiation in a lateral direction; the energy gets spatially redistributed. It is wavelength dependent.

Soil: The topmost layer of the Earth's surface which consists of a mixture of minute particles of weathered rocks, minerals, and organic matter.

Spectral reflectance signature: Spectral reflectance is the ratio of reflected energy to incident energy as a function of wavelength.

Spectral region: The range of wavelength spectrum subdividing the electromagnetic spectrum such as the visible, x-ray, infrared, and microwave regions.

Spectral response: The measurable electromagnetic energy reflected from and emitted by a surface feature.

SPOT: A French remote sensing satellite carrying two push broom imaging systems namely three-waveband multispectral high resolution visible sensor and panchromatic sensor.

Stefan-Boltzmann Law: States that radiant flux of a blackbody is equal to the temperature to the fourth power times the Stefan-Boltzmann constant.

Thematic Mapper: An imaging device carried by Landsats 4 and 5, which records scenes in seven different wavebands; six in the visible and near-infrared and one in the thermal infrared.

Transmission: When radiation passes through a substance without significant attenuation, it is said to be transmitted through the medium.

Vegetation: A general term for all the plant life of a place or region.

Wavelength: Distance between successive wave crests or other equivalent points in a harmonic wave.

Wien's Displacement Law: Describes the shift of the radiant power peak to shorter wavelengths as temperature increases.