Chapter 3

Photogeology, Remote Sensing, and Geographic Information System in Mineral Exploration

Chapter Outline

Mineral Exploration. https://doi.org/10.1016/B978-0-12-814022-2.00003-4

To see a World in a Grain of Sand

And a Heaven in a Wild Flower,

Hold Infinity in the palm of your hand

And Eternity in an hour.

William Blake.

3.1 INTRODUCTION

Shepherds, hunters, traders, and travelers traditionally walked through vast areas of land in ancient days and discovered many deposits because of their natural inquisitiveness. The copper, zinc, lead, gold, and silver deposits of the princely states of India, the Early Dynastic Period of Egypt (3100 BC), Turkey, Israel, Iran, Iraq, Cyprus, and Saudi Arabia were discovered more than 3000 years ago. The Broken Hill zinc-lead-silver deposit was an accidental discovery in NSW, Australia, in 1883 by shepherds looking for tin in gossans. The Sudbury Basin, known for its large Ni—Cu—platinum-group element resources, was reported by a blacksmith in 1883 during construction of the first transcontinental Canadian Pacific Railway. The Bushveld Igneous Complex, the world's largest chromium and platinum group of resources, was discovered in 1897 on a routine geological mapping. The Sukinda chromite deposit, the largest chromium resource in India, was a chance discovery by a tribal villager working for Tata Steel in the early 1940s. Centuries ago explorers traversed the lands by walking or by riding on camels, elephants, and horses looking for geological studies. This involved physically touching/examining rocks and minerals. It was always a difficult mission to approach remote hazardous terrain and often imposed restrictions on precise locations and required detailed mapping.

This physical approach was replaced by remote sensing techniques over a century ago. Since 1920 use of aerial photographic interpretation in the field of Earth sciences became a fast and effective tool for the exploration of natural resources. The science further advanced with the launching of the Landsat-1 satellite in 1972. This made remotely sensed high-resolution digital imagery of the electromagnetic spectrum available for interpretation and use in the commercial exploration of minerals, oil, and gas in the shortest possible time. The first known use of the term "geographical information system" (GIS) was by Roger Tomlinson in 1968. The use of GIS in mineral exploration was the application aspects. The system allows integration of of dissimilar digital datasets into a single and unified database. The recommended approach was to compile all types of available geoscientific data within the GIS envelope in the context of an exploration model to produce a mineral potential map.

Geoscientists had always been fascinated by the bird's eye view of Earth's surface. It helped them to understand and overview its geomorphology, lithology, vegetation, and structures. Geomorphology represents all facets of landform-related aspects. Lithology refers to the fundamental and broad distinction between soils and igneous, sedimentary, and metamorphic rocks. Vegetation focuses upon plant cover and the underlying soils and rocks on which it grows. Geological structures identify the kind of deformation the rocks had undergone such as fractures, shears, folds, faults, and lineaments. These attributes contributed several dimensions to the geological events generated during millions of years. This understanding guided geoscientists to search for minerals and fuels.

Data collection in remote sensing technology records information about an object, area, or phenomenon under investigation without coming in direct physical contact. There are two types of information collection system:

1. Still photographs snapped from space flights or airborne cameras; and
2. Continuous digital recording by multispectral electronic scanners or sensors from airplanes or satellites.

3.2 PHOTOGEOLOGY

Photogeology is the simplest approach to remote sensing techniques and their applications. It is the derivation of geological information from the interpretation of aerial photographs. Gaspard-Félix Tournachon (known by the pseudonym Nadar, a French photographer) was the first to suggest the use of aerial photographs taken from a captive balloon in 1858 for the preparation of topographic and cadastral maps. Albert Heim (1898) made a balloon flight over the Alps. He expressed that the structures were more clearly defined in the aerial view. Wilbur Wright took the first photograph from an airplane in 1909 and opened the door to photogeology. World War I (1914—18) had a tremendous influence on the development of aerial photography and its adaptation to common reconnaissance and the needs of surveillance. The science of photointerpretation was born. Many of its basic techniques were developed during the 1920s and expertise improved during World War II (1940—45). Development continued through the 1940s and 1960s approaching its highest capabilities. Growth finally assimilated into the newly developing geological remote sensing.

The camera has come a long way through the process of evolution since it was first invented in the early 1800s. It used direct sunlight that penetrates through a pinhole forming a conical shape in reverse to the object on the opposite wall of a dark room. This was modified and the pinhole was replaced by a lens. The image was recorded on a glass plate in the box. The first black and white (B&W)

photograph was reported in 1814. The crucial starting point in the history of the camera began in 1837 with a permanent photograph using visible light or rays. The first color photograph was produced on a glass plate in 1907. In the early 1940s commercially successful color photographs were produced on film. The quality of photographs was improved by introducing wide angle lenses and filters. The digital single lens reflex camera was first produced in 1981 and is the most recent addition to the world of high-resolution cameras, which provide more features than any other camera ever produced. Digital cameras hold photographs on a memory card, which allows one camera to hold over 100 photographs. Digital cameras have become increasingly popular over the last few years and are being continuously modified to be smaller (mounted on a cellular phone) and faster with 12.4 million pixels, like that mounted in NASA's space shuttle in 2008.

Aerial photography started with cameras fitted on hydrogen-filled balloons, pigeons, kites, parachutes, helicopters, fixed-wing aircraft, and the space shuttle. The camera takes photographs of the ground from a higher horizon without any ground-based support. The cameras may be handheld or firmly mounted on a stand or board. The images taken may be triggered remotely or automatically. Aerial photographs are usually taken between mid-morning and mid-afternoon when the sun is high with minimal shadow effect.

3.2.1 Classification of Aerial Photographs

Aerial photographs are classified on the basis of camera axis, i.e., oblique and vertical, type of film emulsion, and scale.

3.2.1.1 Oblique Photographs

Photographs can be snapped at either a high or low angle oblique camera position to the objects. The high angle oblique photographs include the horizon. The oblique photographs are handy to obtain permanent records of inaccessible mountain cliffs, canyons, gorges, steep angle quarry faces, dam sites, and similar features. These photographs can be studied to identify stratigraphy, rock color and texture, erosion, fold, fault, and linear structures. The information is valuable during mineral search and while attaining corrective measures of structural failures.

3.2.1.2 Vertical Photographs

Vertical photographs are taken by a camera pointing vertically downward, and the axis of the camera/lens is perpendicular to the ground. Aerial photographs show a perspective view due to the effect of distortion on account of image motion, displacement, change in topography, and effect of parallax. The principal point/plumb point/nadir or geometric center has no image displacement. It is the point on the photograph that lies on the optical axis of the camera and is determined by joining the fiducial marks recorded on the photograph (Fig. 3.1).

Flight lines are the paths that an aircraft takes to ensure complete coverage of the area to be photographed. The flight lines are arranged to give a succession of overlapping photographs (Fig. 3.1) to minimize distortion. The photographs overlap within and between the flight lines. The overlaps in these two directions are called forward overlap (end lap) and side lap. The forward overlap along the flight line between two adjacent photographs (stereo pairs) is about 60% to provide complete coverage and a stereoscopic view of the area. The forward overlaps between the first, second, and third adjacent photographs are 60% and 30%, respectively. The side lap between flight lines is usually about 30% to ensure that no areas are left uncovered. A nadir line is a line traced on the ground directly beneath an aircraft while taking photographs of the ground from above. This line connects the image center of the successive vertical photographs. The nadir line is rarely in straight line format due to changes in flight travel course, and needs necessary correction. The title strip of each photograph frame includes flight, line, and photograph number, date and time of the exposure, bubble balance, sun elevation, flight height, and focal length of the camera.

3.2.1.3 Film Emulsion

Aerial photos are coated with unique film emulsion and can be grouped as:

1. Panchromatic black and while (B&W).
2. Infrared black and white (IR).
3. Color (true).
4. IR color or false-color composite (FCC).

A true-color image of an object is the same color as it appears to human eyes—a green tree appears green and blue water appears blue. True color for B&W images perceive lightness of the object as the original depiction. A false-color IR image of an object depicts complementary colors that differ from original colors as appears to human eyes: vegetation, forest, and agricultural land depict red in lieu of original green color.

3.2.1.4 Scale

There are four broad groups of scale to distinguish aerial photographs: small, medium, large, and very large. A large-scale map indicates that the representative fraction (RF) is large, i.e., the RF's denominator is small. 1:10,000 and 1:2500 maps are large scale. Small-scale maps have a small RF. 1:250,000 and 1:50,000 maps are small scale.

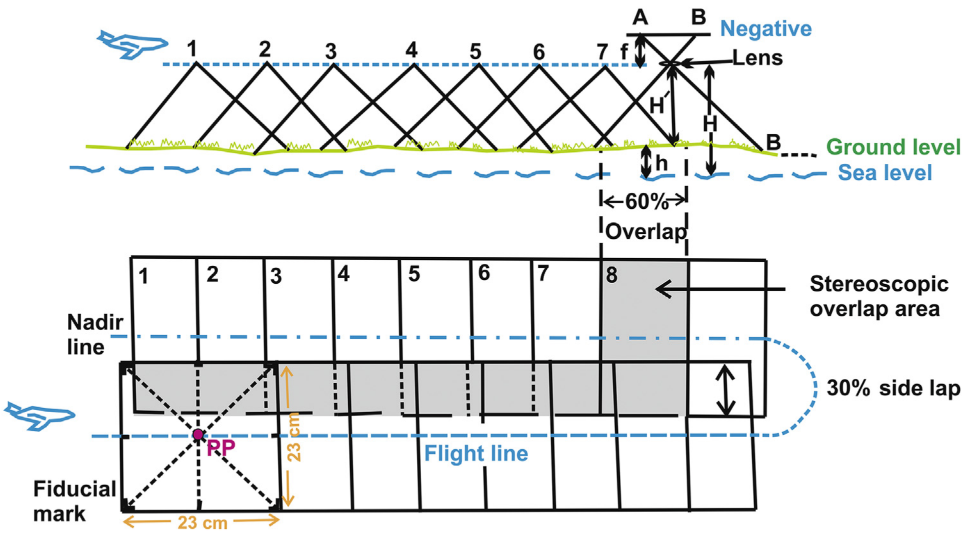

FIGURE 3.1 Schematic typical photograph coverage over flat terrain showing forward overlap and side lap, nadir, flight line, principal point, and fiducial mark.

1. Small scale: ≥1:50,000−1:250,000: reconnaissance
2. Medium scale: 1:10,000−1:50,000: prospecting
3. Large scale: 1:2000−1:10,000: detail exploration
4. Very large scale: ≤1:2000: mine exploration

The rule of thumb is "the larger the scale of map, the larger the objects with more detail features and better resolution."

Scale is the ratio between a distance of two points on the aerial photograph and the distance of the same points on the ground. The unit of scale is expressed as an equivalent (1 mm = 1000 mm) or dimensionless fraction (1/1000) or dimensional ratio (1:1000). In a vertical aerial photograph the scale is a function of the focal length (f) of the camera and the flying height above the average ground level (H′) of the aircraft. The aircraft flies at a nearly constant height. The scale will be constant as and when the plane flies over a flat terrain. In the case of flying over undulating mountainous terrain the scale will vary rapidly across the adjacent photographs. Therefore the scale of aerial photography is a function of terrain elevation.

$$\text{Scale (S)} = f/H'$$

where H′ is the difference between the terrain elevation (h) and height of the aircraft above a datum (H), usually the mean sea level value available from the altimeter in the aircraft.

Following Figure 3.1,

Focal length (f) = 50 cm.

Aircraft height above datum (H) = 5500 m.

Terrain height (h) = 50 m.

Scale (S) = 50 cm/(5500−500) m = 50 cm/500,000 cm = 1/10,000 or 1:10,000.

3.2.2 Parallax

Parallax is an apparent displacement or difference of orientation of an object viewed at two different locations during vertical aerial photography. The objects at a higher height lie closer to the camera and appear relatively larger than similar objects at a lower elevation. The tops of the objects are always displaced relative to their bases. Parallax can be measured by the angle of inclination between those two lines. Nearby objects have larger parallax than distant objects when observed from different positions. This difference in parallax gives a three-dimensional effect when stereo pairs are viewed stereoscopically.

3.2.3 Photographic Resolution

The resolution of aerial photographs depends on various factors such as:

1. The effect of scale is closely related to ground distance from the camera, i.e., the closer the distance, the higher the resolution.
2. Correct exposure time will give higher resolution while using slow and fast film.
3. Higher resolving power of the camera lens will give better results.
4. Movement of the camera lens during exposure must be minimized.
5. Vibration of the camera and aircraft should be minimal for better resolution.
6. Resolution will also change depending on atmospheric conditions at the time of filming and quality of film processing.
7. Precise film processing.

3.2.4 Problems of Aerial Photography

There are a few inherent problems particularly related to aircraft movement. An aircraft usually deviates from the line of flight, altitude, and tilting of wings resulting in drifting of photographs, change of scale between adjacent frame, distortions, and resolution of photographs.

3.2.5 Photographic Interpretation

The mirror stereoscope, color additive viewer, and electronic image analyzer are widely used equipment for aerial photographic interpretation.

A set of two photographs (23 × 23 cm), shot from two successive points, is viewed using the stereoscope. A three-dimensional (3D) mental model is perceived when the two images merge into each other. This enables a viewer to see a two-dimensional (2D) image that is actually two separate images printed side by side with common overlapping areas in three dimensions. The features in the photographs are verified with field observations.

Modern instruments are the color additive viewer and the electronic image analyzer. In the case of the color additive viewer, multispectral photographs are taken simultaneously using three or four cameras in a narrow spectral band of 0.4−0.5 (blue), 0.5−0.6 (green), 0.6−0.7 (red), and 0.7−0.9 (IR) μm. An FCC is generated by superimposition of multispectral photographs. The human eye will differentiate and interpret color composite more so than gray tones. The electronic image analyzer scans B&W aerial photographs and produces close circuit video digital images for interpretation.

3.2.6 Application in Mineral Exploration

Systematic evaluation, interpretation, and identification of key parameters from aerial photogeology have applications for society in general and mineral exploration in particular. The key information and applications include:

1. Topography, surface erosion, land distribution, drainage system, and land-use pattern that support urban and agricultural planning.
2. Soil and rock types (host environment), texture, structures (fold closure, faults, shears, and lineaments), and surface signatures (weathering profile, gossans, and old mining/smelting remnants) contribute to conceptualize the existence of near-surface/deep-seated deposits as possible exploration targets (Fig. 3.2).
3. Vegetation with prolific/scanty growth, anomalous colors, and toxic effects along with drainage pattern guide planning geochemical sampling.
4. Approach is more significant for mineral deposits occurring at remote inaccessible areas.

FIGURE 3.2 A typical aerial view of the Colorado River in the background from a height of 7000 feet from Southern Rim, Grand Canyon, Natural Wonders of the World, Arizona.

3.3 REMOTE SENSING

3.3.1 Definition and Concept

Remote sensing is an emerging expertise that has undergone phenomenal development over aerial photography and interpretation. It is a comprehensive process of collecting information about an object, area, and phenomenon without coming in direct contact or touching itself. The information is acquired by a remotely placed sensor far away from the source object. Remote sensing implies data acquisition by electromagnetic radiation from sensors flying on aerial or space platforms and interpretation of physical attributes of ground objects (Campbell, 2007). The fundamental difference between photogeology and remote sensing is the same as between photographs and images. Photographic data are the reflection of natural light recorded on a light-sensitive emulsion-coated base film (negative) and printed on light-sensitive emulsion-coated paper (positive/paper print) for interpretation. Image data are the reflected and emitted multispectral electromagnetic energy recorded directly in digital form on a magnetic tape or disk. The soft copy is processed and interpreted. The remote sensing data captivate the maximum capability, liberty, and flexibility for manipulation of multispectral responses over photogeology.

The remote sensing technique involves each type of object reflecting or emitting a certain intensity of energy as and when in contact with a different range of wavelengths of the electromagnetic spectrum, depending on the physicochemical attributes of the object. The multispectral images in green, red, and near-IR bands can distinguish between different types of objects like water, soil, rocks, surface weathering, and vegetation (Lillesand and Kiefer, 2003; Gupta, 2003; Evans, 2006).

3.3.2 Energy Sources and Radiation

3.3.2.1 Electromagnetic Energy

Visible light, one of the many forms of electromagnetic energy (EME), with wavelength (λ) varying between 0.4 and 0.7 μm, is sensed by the human eye. The human brain receives color impulses of visible objects from the eyes via three separate light receptors in the retina. These receptors respond to blue, green, and red light, and are known as additive primaries or primary colors. The receptor systems stimulate equally to white visual effects if these three colors overlap. A relative mixing of three primary colors reflected from the object changes to a full range of rainbow colors, i.e., violet, indigo, brown, green, yellow, orange, and red. The eyes perceive “a bowl of fruits” as visible light by synthesizing.

The other wavelengths ranging between 0.7 and 300 μm are longer than visible ray, and known as IR. IR is divided into various components with respect to increasing wavelength. These are near IR (NIR λ 0.7−1.1 μm), middle IR (MIR λ 1.1−3.0 μm), far IR (FIR λ 7−17 μm), and thermal IR (TIR λ 3.0−5.0 μm). Color NIR beams generate three supplementary colors, namely, cyan, magenta, and yellow.

There are two principal types of energy (EME), namely, light energy as reflected and heat energy as emitted from the object after partial absorption. Data acquisition in remote sensing technology works on this concept of transmitting rays/energy at various wavelengths and receiving the relative reflectance and emitted energy to distinguish the characteristic attributes of objects under investigation.

The ultraviolet ray (λ 3 nm−0.4 μm) transmits heat energy that burns human skin and affects the eyes. The transmission of IR energy at λ 8−14 μm emits less than 200°C and is suitable for a thermal spring. Similarly, IR energy at λ 3−5 μm emits more than 200°C and is suitable for volcanic study. Microwaves with 0.8−100 cm wavelength can penetrate into cloud and even the subsurface. Various rays/energies and their characteristic wavelengths can be found in Table 3.1.

TABLE 3.1 Various Rays/Energies and Their Characteristic Wave Lengths

Ray	Wavelength	Ray	Wavelength
Gamma ray	<0.03 nm	Photographic IR	0.7−3 μm
X-ray	0.03−3 nm	NIR (magenta, cyan, and yellow)	0.7−1.3 μm
Ultraviolet ray	3 nm −0.4 μm	MIR	1.3−3.0 μm
Visible ray	0.4−0.7 μm	FIR (thermal and emissive)	7−17 μm
Blue	0.4−0.5 μm	TIR (forest fire)	3.0 −15.0 μm
Green	0.5−0.6 μm	Microwave	0.3−300 cm
Red	0.6−0.7 μm	Television/radio waves	1.5 km
Infrared	0.7−300 μm	Electromagnetic radiation	0.74 −300 μm

1 nm = 10^{-9} m, 1 μm = 10^{-6} m. *FIR*, Far infrared; *MIR*, mid-infrared; *NIR*, near infrared; *TIR*, thermal infrared.

3.3.2.2 Electromagnetic Radiation

Electromagnetic radiation is a phenomenon that takes the form of self-propagating energy waves as it travels through space (vacuum or matter). It consists of both electric and magnetic field components. The energy waves oscillate in phase perpendicular to each other and perpendicular to the direction of energy propagation. It is observed that the longer the wavelength involved, the lower would be the frequency as well as the energy. Electromagnetic radiation is classified into several types according to the frequency of its wave. These types include (in order of decreasing frequency and increasing wavelength) cosmic radiation, gamma radiation, X-ray radiation, ultraviolet radiation, visible radiation, IR radiation, terahertz radiation, microwave radiation, and radio waves. A small and variable window of frequencies is sensed by the eyes of various organisms. This is known as the visible spectrum (λ 0.4−0.7 μm) or light. Electromagnetic radiation carries energy and momentum that may be imparted to matter with which it interacts.

A black body is an inclusive part of electromagnetic radiation, and is an idealized theoretical radiator that absorbs 100% of all electromagnetic radiation that hits it (Box 3.1).

Electromagnetic radiation propagation travels the path length twice between the source, object, and sensor through the total thickness of the atmosphere. The compositional nature of the atmosphere affects the propagating energy by partial absorption and scattering. Atmospheric absorption results in the effective loss of energy to atmospheric constituents. The most efficient atmospheric absorptions are water vapor, carbon monoxide, carbon dioxide, and ozone. The unpredictable diffusion of radiation by particles within the atmosphere is called atmospheric scattering. Atmospheric windows are the ranges of wavelength in which the atmosphere is particularly transmissive.

3.3.2.3 Electromagnetic Spectrum

The electromagnetic spectrum is a collective term referring to the entire range and scope of frequencies of

BOX 3.1 Black Body

A black body is a perfect theoretical radiator that absorbs 100% of all electromagnetic radiation that hits it. No electromagnetic radiation passes through it and none is reflected. The object appears completely black when it is cold because no light (visible electromagnetic radiation) is reflected or transmitted. There is no material in nature that completely absorbs all incoming radiation. However, graphitic carbon absorbs 97% incoming radiation, and is the perfect emitter of radiation. A black body emits a temperature-dependent spectrum (thermal radiation) of light, and is termed black-body radiation. A black body emits the maximum amount of energy possible at a particular temperature.

electromagnetic radiation. The behavior of radiation depends on its wavelength and is inversely proportional to frequency and wavelength, i.e., higher frequencies have shorter wavelengths and vice versa. The electromagnetic spectrum of an object is the characteristic distribution of electromagnetic radiation emitted or absorbed by that particular object. The complete range of the electromagnetic spectrum is elaborated in Fig. 3.3.

3.3.2.4 Spectral Reflectance/Response Pattern

The difference between the intensity of electromagnetic radiation reflected or emitted by an object at different wavelengths is called spectral response or signature. The curve generated by the intensity of energy versus wavelength is called the spectral response curve. A single feature or a response pattern can be diagnostic in identifying an object.

3.3.2.5 Data Acquisition

Data detection and acquisition are performed either photographically or electronically. The process of photography relies on chemical reaction on light-sensitive film. The electronic process administers electromagnetic signals to the objects. The electromagnetic signals are fed back to the sensors with a broader spectral range of sensitivity and are capable of storing and transmitting as and when required. Most of the data acquisition in remote sensing is synonymous with multispectral satellite imagery as detailed in Table 3.2. These images received from satellites are readily available to exploration agencies at a cost.

3.3.3 Remote Sensing System

For better understanding and utility a model remote sensing system comprises the following components:

3.3.3.1 Platform

Platforms are vehicles or carriers that carry the remote sensor. Typical platforms for remote sensing data acquisition are terrestrial (ladders and trucks for ground investigations), aerial (kites, balloons, helicopters, and aircraft for low-altitude remote sensing), and space-borne (manned or unmanned rockets and satellites from high altitude). The key factor for the selection of a platform is altitude, which determines the best possible ground

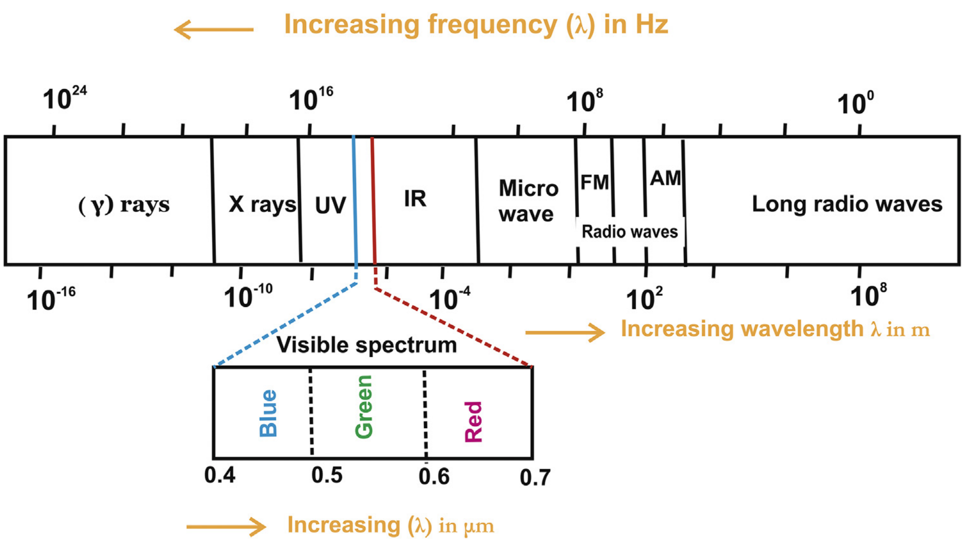

FIGURE 3.3 A complete possible range of electromagnetic spectrum with increasing frequency.

TABLE 3.2 Salient Features and Chronological Development of Major Landsat Type Earth-Resources Satellite Platforms Over Four Decades

Satellite	Country	Year	Nature	Altitude (km)	Sensor
Landsat-1	USA-NASA	1972	Sun Sys	919	MSS, RBV
Landsat-2	USA-NASA	1975	Sun Sys	919	MSS, RBV
Landsat-3	USA-NASA	1978	Sun Sys	919	MSS, RBV
Landsat-4	USA-NASA	1982	Sun Sys	705	MSS, TM
Landsat-5	USA-NASA	1984	Sun Sys	705	MSS, TM
SPOT-1	France	1986	Sun Sys	832	HRV
IRS-1A	India	1988	Sun Sys	904	LISS-1
IRS-1B	India	1991	Sun Sys	904	LISS-2
Landsat-6	USA (EOSAT)	1993	Sun Sys	705	ETM
SPOT-3	France	1993	Sun Sys	–	HRV
IRS-1C	India	1995	Sun Sys	817	LISS -3
IRS-1D	India	1997	Sun Sys	817	LISS -3
SPOT-4	France	1998	Sun Sys	832	HRV IR
IRS P7	India, ISRO	2007	Sun Sys	–	LISS-4
Landsat-7	USA-NASA	1999	Sun Sys	705	ETM+
Terra	USA–Japan	1999	Sun Sys	713	ASTER, etc.
RADARSAT-2	Canada	2008	Sun Sys	798	SAR
Landsat-8	USA-USGS	2013	Sun Sys	705	TIRS
SPOT-7	France	2014	Sun Sys	660	HRV IR
Cartosat-2E	India, ISRO	2017	Sun Sys	505	IRS

IRS, Indian Remote Sensing Satellite system; *NASA*, National Aeronautics and Space Administration (USA); *SPOT*, Satellites Pour l'Observation de la Terre (France).

resolution and which is also dependent on the instantaneous field of view (IFOV) of the sensor on board the platform.

The first Landsat-1 satellite was launched in July 1972 by NASA, USA. This was originally named Earth Resources Technology Satellite and provided multispectral imagery for the study of renewable and nonrenewable resources. Landsat-4 (1982) incorporated Thematic Mapper, which scanned in seven bands, two of which (5 and 7) were specifically opted for geological purposes. A great variety of satellites were built for monitoring various environmental conditions on land and at sea. Satellites can view Earth in vertical, side, or limb modes. The new methodology of Earth science is based on satellite data that allows a whole Earth approach to study the environment. The remotely sensed satellite data and images of Earth have four important advantages compared to ground observations, such as synoptic view, repetitive coverage, multispectral capability, and low-cost data.

India began development of an indigenous Indian Remote Sensing (IRS) satellite program to support the national economy in the areas of agriculture, water resources, forestry and ecology, geology, water sheds, marine fisheries, coastal management, weather forecasting, natural calamities, and disaster management. IRS satellites are the mainstay of the National Natural Resources Management System, for which the Department of Space is the nodal agency, providing operational remote sensing data services. Data from the IRS satellites are received and disseminated by several countries all over the world. New applications in the areas of urban sprawl, infrastructure planning, and other large-scale applications for mapping have been identified with the advent of high-resolution satellites. The salient features of some important Landsat-type Earth resources satellite platforms of the 20th century are given in Table 6.2.

The path of a celestial body or an artificial satellite as it revolves usually in an elliptical path around another body is called an orbit. Earth satellites make one complete revolution in 12 h. There are two types of orbit, i.e., polar and equatorial orbits.

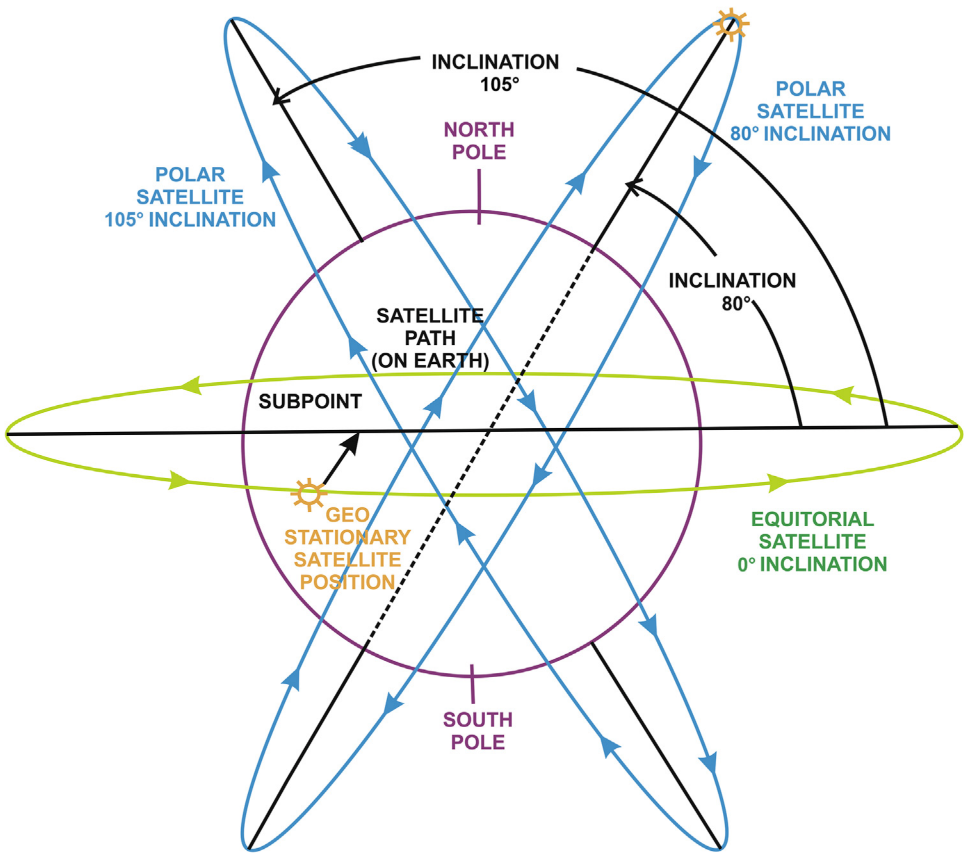

FIGURE 3.4 Diagram showing the typical elliptical orientation path of Earth's satellites, known as polar and equatorial orbits.

In the case of a polar orbit the satellite travels over both North and South Poles at about 850 km altitude above Earth at an angle of 80 and 105 degrees from the equatorial plane (Fig. 3.4). North to south rotation is called descending and south to north rotation is called ascending. The satellites take about 100 min for a complete revolution in polar orbit. They can see a small portion at a time covering the whole globe at high resolution. The polar orbit is essentially sun synchronous and geostationary. A satellite in such an orbit can observe all points on Earth during a 12-h day. This type of orbit is useful for spacecraft that perform mapping or surveillance.

In the case of an equatorial orbit the satellite flies along the line of Earth's equator (Fig. 3.4). A satellite must be launched from a place on Earth close to the equator to achieve equatorial orbit. Equatorial orbits are useful for satellites observing tropical weather patterns because they can monitor cloud conditions around the globe.

A sun-synchronous orbit (heliosynchronous or dawn-to-dusk orbit) is a geocentric orbit that combines altitude and inclination in such a way that an object on that orbit ascends or descends over any given point of Earth's surface at the same local mean solar time. The surface illumination angle will be nearly the same every time. This consistent lighting is a useful characteristic for satellites that image Earth's surface in visible or infrared wavelengths and for other remote sensing satellites, e.g., those carrying ocean and atmospheric remote sensing instruments that require sunlight.

A geostationary orbit is a geosynchronous orbit directly above Earth's equatorial orbit (0 degree latitude and 36,000 km altitude) and stays over the same spot with a period equal to Earth's rotational period. Geostationary objects appear motionless in the sky from Earth's surface, making the geostationary orbit of great interest for communication purposes and weather forecasting. It observes an evolving system with lower spatial resolution. The satellites in geostationary condition differ in location by longitude only, due to the constant 0 degree latitude and circularity of geostationary orbits.

3.3.3.2 Sensors

Sensors are devices like photographic cameras, scanners, and radiometers mounted on suitable platforms to detect and record the intensities of electromagnetic radiation in various spectral channels. Sensors are of two types: passive and active.

Passive sensors are designed to record data using an available naturally occurring energy source reflected,

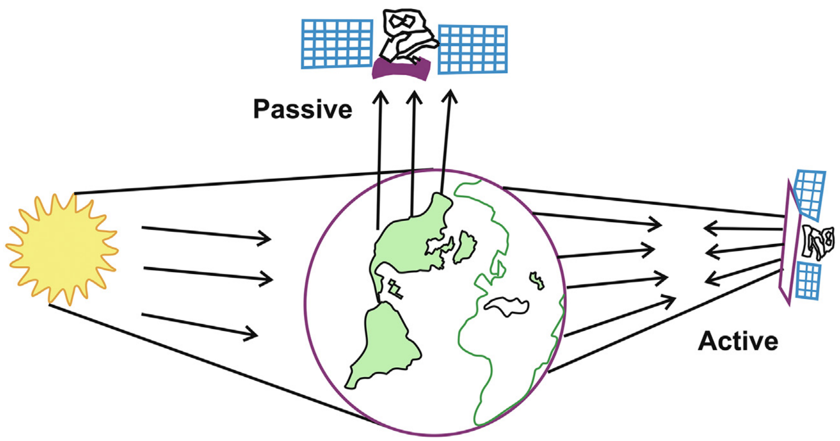

FIGURE 3.5 Schematic diagram showing the position of a data collecting device with respect to Sun and Earth to designate it as a passive or active sensor.

emitted, and transmitted by parts of the electromagnetic spectrum. They rely on the solar illumination side of Earth or natural thermal radiation for their source of energy (Fig. 3.5). The detection of reflected solar energy can only proceed when the target is illuminated by the Sun. This restricts visible light sensors on satellites from being used during a nighttime pass. Examples of passive sensors are Landsat Multispectral Scanner, Landsat Thematic Scanner using additional wavelengths to produce superior spectral and spatial resolution, the airborne scanning system SPOT with stereoscopic capabilities, and the space shuttle.

Active sensors use their own illumination as source of energy and can make observations on both the sunlit as well as the dark side of Earth regardless of the time of day or season (Fig. 3.5). The sensor emits radiation that is directed toward the target to be investigated. The radiation reflected from the target object is received and recorded by the sensor. An active system requires the generation of a fairly large amount of energy to adequately illuminate the targets. Some examples of active sensors are a Synthetic Aperture Radar (SAR) and laser fluorosensor.

3.3.3.3 Sensor Resolution

Remote sensing sensors have four types of resolution, namely, spatial, spectral, radiometric, and temporal:

1. Spatial resolution includes the geometric properties of the ground covered under the IFOV of the sensor. IFOV is defined as the maximum angle of view in which a sensor can effectively detect electromagnetic energy (imaging).
2. Spectral resolution is the span of the wavelength over which a spectral channel operates by the sensor. It is defined by the bandwidth of the electromagnetic radiation of the channels.
3. Radiometric resolution is the degree of intensities of radiation the sensor is able to distinguish.
4. Temporal resolution involves repetitive coverage over an area by the sensor and is equal to the time interval between successive observations. Repeated coverage will identify changes in the objects under study.

An ideal remote sensing system should fulfill the following criteria:

1. Uniform energy source of all wavelengths at a constant high level of output, irrespective of time and place.
2. Clean atmosphere between the source, target, and receiver for to and fro energy radiation.
3. Sensitive super-sensor for acquisition of data.
4. Real-time data processing and interpretation system.

Multidisciplinary users having adequate knowledge, skill, and experience of remote sensing geographical information system (RS-GIS) data acquisition and analysis and can extract their own information.

3.3.4 Characteristics of Digital Images

3.3.4.1 Pixel Parameters

In digital imaging, a pixel (picture element) is the smallest item of information in an image. Each pixel is represented by a number equivalent to average radiance or brightness of that very small area. Pixels are normally arranged in a 2D grid (x, y) and are often represented using dots or squares. The "z" value represents the grayscale value of 256 different brightness levels between 0 (black) and 255 (white). Each pixel is a sample of an original image, where more samples provide more accurate representations of the original object. Pixel size determines the spatial resolution. The intensity of each pixel is variable in a color system, and each pixel has typically three or four components such as red/green/blue or cyan/magenta/yellow and black. An image is built up of a series of rows and columns of pixels.

3.3.4.2 Mosaics

Each image has a uniform scale and resolution for a scan path with forward and side overlap. A mosaic is a set of images arranged to facilitate a bird's eye view of an entire area. This is done by cutting and merging each overlapping scene image.

3.3.5 Digital Image Processing

Multispectral satellite sensor data are collected and stored in digital form on computer compatible magnetic tapes at a ground station for processing. The mineral exploration data are upgraded to image restoration, enhancement, and information extraction.

3.3.5.1 Image Restoration

Image restoration is correcting defects/defiance in images during data collection and subsequent transfer to a ground station. The process involves replacing lost data (pixel and line), filtering of atmospheric and other noises, and geometrical correction.

3.3.5.2 Image Enhancement

Image enhancement is the procedure of improving the quality and information content of original data before processing. Common practices include contrast enhancement, spatial filtering, density slicing, and FCC. Contrast enhancement or stretching is performed by linear transformation expanding the original range of gray level. Spatial filtering improves the naturally occurring linear features like fault, shear zones, and lineaments. Density slicing converts the continuous gray tone range into a series of density intervals marked by a separate color or symbol to represent different features.

FCC is commonly used in remote sensing compared to true colors because of the absence of a pure blue color band because further scattering is dominant in the blue wavelength. The FCC is standardized because it gives maximum identical information of the objects on Earth and satisfies all users. In standard FCC, vegetation looks red (Fig. 3.6) because vegetation is very reflective in NIR and the color applied is red. Water bodies look dark if they are clear or deep because IR is an absorption band for water. Water bodies give shades of blue depending on their turbidity or shallowness because such water bodies reflect in the green wavelength and the color applied is blue.

3.3.5.3 Information Extraction

Information extraction is carried out online by ratioing, multispectral classification, and principal component analysis to enhance specific geological features. The ratio is

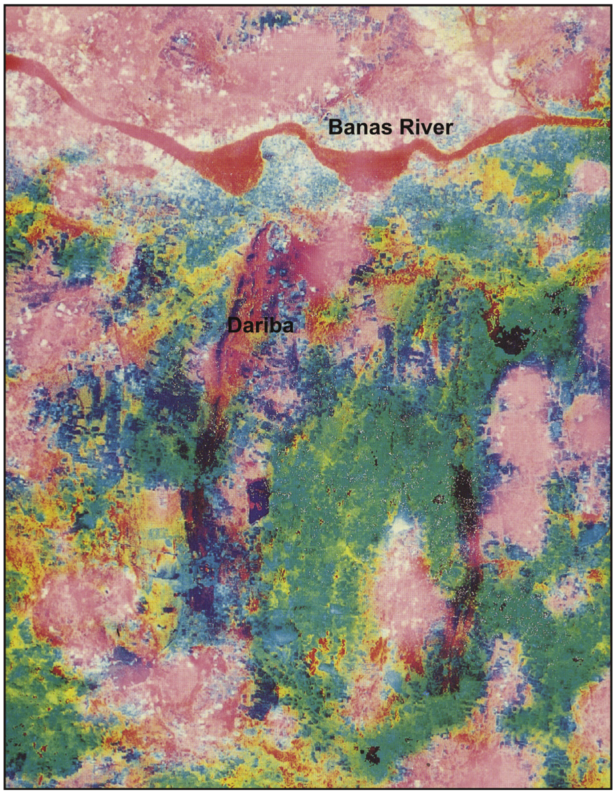

FIGURE 3.6 False-color composite image of aeromagnetic and satellite data over Rajpura-Dariba sulfide belt, Rajasthan, India.

prepared by dividing the gray level of a pixel in one band by that in another to recognize ferruginous and limonitic capping (gossans) useful for identifying sulfide deposits. Multispectral classification generates small groups of pixels of different reflectance, and is marked by different colors or symbols to represent the same kind of surface signature. Principal component analysis is a commonly used method to improve the spread of reflectance by redistributing it. It is used to enhance or distinguish the difference in geological features (Fig. 3.7), e.g., elevation, land cover, lineaments, rock types, vegetation index, turbidity index, forest fire, flood, and archaeological features.

3.3.6 Interpretation

Remote sensing data interpretation or extraction of information from processed satellite images is usually done by photogeological or spectral approaches. Each frame of Earth cover image has its own spectral reflectance characteristics. The characteristics ("signature") are unique and make it possible to distinguish the objects of interest from their intermixed background. The final process is completed by the analysis of the data or images using image interpretation techniques. The techniques of remote sensing and image interpretation yield valuable information on Earth resources.

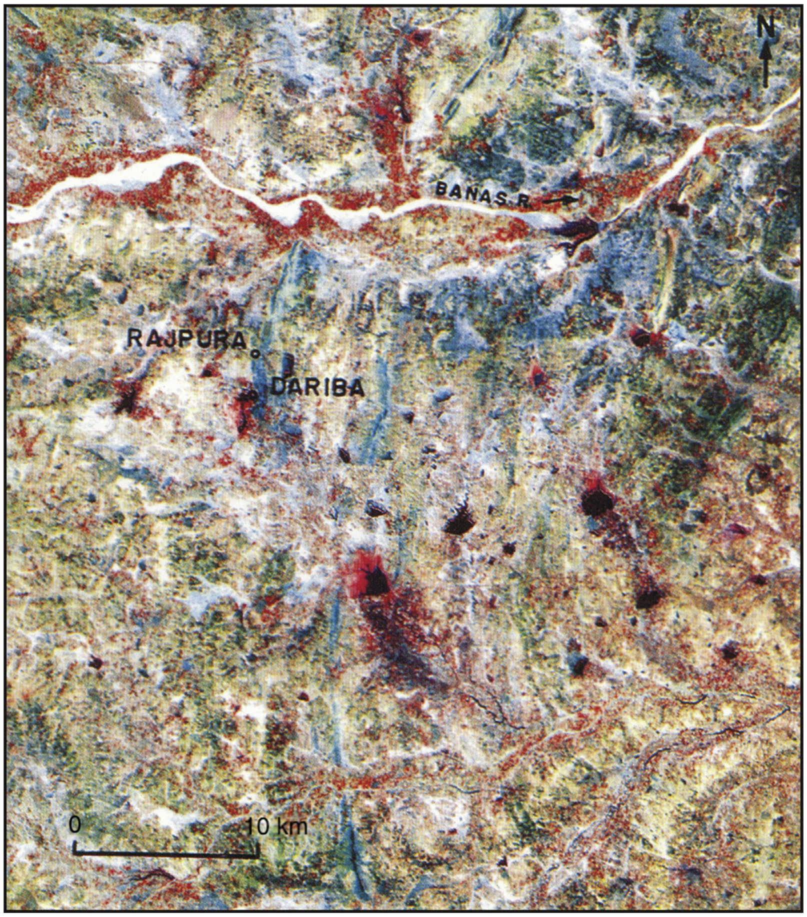

FIGURE 3.7 Principal component image of Rajpura-Dariba sulfide belt, Rajasthan, India.

3.3.7 Remote Sensing Application in Natural Resources

Multispectral remote sensing techniques have significant potential for multipurpose applications in all branches of Earth science, such as geomorphology, structure, litho mapping, and stratigraphic studies. Many applications are closely related to mineral exploration and resource estimation, and form a concept-based synoptic overview to locate and delineate mineral-bearing provinces, including hydrocarbon and water at reduced time and cost. Remote sensing applications play a significant role at all the sequential stages of exploration, starting from reconnaissance, large area prospecting, prospecting, detailed exploration, active mining, and geoenvironment to mine closure (Taranik, 2009). The applications are:

1. The most powerful data sources at the reconnaissance or preliminary stage of mineral search are satellite-based images at small scale (1:50,000 or 1:250,000). The objective is to identify metallogenic provinces out of an extremely large license area. The targets can be checked by limited test drilling. The explorer then moves to the prospecting stage using photogeology (1:25,000 or 1:50,000), supplemented by aerial geophysics to identify anomalies representing possible target(s) for systematic drilling. At this juncture thematic map generation is useful for prioritization of exploration targets. The prospecting activities lead to detailed exploration by detail mapping (1:10,000, 1:5000, 1:2,000), ground geochemistry, geophysics, and close space diamond or reverse circulation drilling to estimate the reserves and resources. The environmental baseline maps generated at the initiation of exploration can be useful and compared with the mine closure plan for environmental restoration of the ecosystem.
2. The remote sensing study of geomorphology reveals various types of land forms (tectonic, volcanic, fluvial, coastal and deltaic, aeolian, and glacial). The salient guides are predominantly surface indications like sustained weathering and erosion (residual and supergene enrichment), oxidation (gossans), remnants of ancient mining/smelting activities, drainage pattern (stream sediment sampling), placer deposits (diamond, gold,

ilmenite, and monazite) formed as a result of mechanical concentration of fluvial, aeolian, alluvial, eluvial, and marine processes. A long continuous belt of placer deposits around the east and west coast of India, Indonesia, and Australia are identified from remote sensing data.

3. The aerial and space base acquired data provide a completely new dimension to mineral exploration by integration of structural (rings, folds, faults, shear zones, and lineaments) data into a composite aerial view. These structures in many cases are the governing factors in localization of economic mineral deposits. The identification of rings, shear zones, and lineaments using RADARSAT images help to find areas with the probability of diamond pipe and base-metal mineralization. The final structure layer is prepared using visual interpretation and software processing.
4. The remote sensing data generate broad-scale litho maps, including mineral assemblages and formation of a stratigraphic succession model. Mineral deposits have a certain affinity to particular groups of host rocks, e.g., base metals with dolomite, calc-silicate and black schist, phosphorites with dolomite, iron with banded hematite quartzite, and coal with shale and sandstone. Similarly, some minerals are closely related to a certain stratigraphic age group, e.g., gold with Archean green schist horizon (>2500 Ma), coal with Permo-Carboniferous (248−360 Ma), and hydrocarbon with Cretaceous (65−144 Ma) ages. Some mineral deposits are preferentially confined to the genetic aspects of rock types, e.g., >60% of zinc-lead deposits is related to Proterozoic SEDEX type. The interpretation of remote sensing data serves as a useful guide during mineral exploration by identification of these critical features.
5. The dense vegetation masking the surface at remote locations may make mineral exploration difficult. Information collected from remote sensing platforms can reveal the reality below the ground. The relative geobotanical abnormalities in vast areas can be easily detected and mapped from aerial view. Two types of anomalies are common in the growth of vegetation. The morphological features include changes in the color of leaves and flowers, and dwarfing due to the toxic effect of metals in the soil. Taxonomic differences refer to relative abundance or absence of certain species.
6. The groundwater search requires identification of aquifers located a few meters to hundreds of meters from the surface. Surface features can be mapped by remote sensing leading to regional/local groundwater maps. Electromagnetic radiation and microwave can barely penetrate a few meters into the ground. This causes limitation of data acquisition and use of remote sensing as a direct guide for deep-seated groundwater exploration. Many of the surface features responsible for subsurface water conditions can be mapped by remote sensing leading to regional and local groundwater maps. The regional groundwater survey can be interpreted from a second-order indirect indicator, namely, landforms, rock types, soil moisture, rock fractures, drainage characteristics, and vegetation. The local exploration indicators are obtained from first-order direct signatures of recharge and discharge zone, soil moisture, and anomalous vegetations.
7. Hydrocarbons (oil and gas pools) exist kilometers below the surface and are confined to suitable stratigraphy and/or structural traps. Hydrocarbon exploration by multispectral remote sensing data acquisition depends on second-order indirect evidence like striking circular drainage anomalies, geobotanical and tonal anomalies due to seepage of underlying hydrocarbons, regional lineaments in oil-bearing regions, and films of oil slicks on ocean and sea water surfaces.

A remote sensing data interpreter has to rely on direct or indirect clues such as general stratigraphic setting, alteration and oxidation zones, favorable host rock assemblages, rings/folds/faults/shears/lineaments, morphology, drainage patterns, and effect on vegetation to guide the exploration rapidly. Alteration and structure along with other information layers, i.e., geo maps, geophysics, and geochemistry, are used to produce the primary exploration model in GIS. The best results are achieved by giving higher weights to the remote sensing layers. The quality of results is evaluated by field checking. Remote sensing interpretations are highly reliable in mineral exploration.

To conclude, mineral potential mapping is a systematic plan to collect, manage, and integrate various geospatial data from different sources and scales during multistage activity. GIS can describe, analyze, and interact to make predictions with models and provides support for decision makers.

3.4 GEOGRAPHIC INFORMATION SYSTEM

3.4.1 Definition

GIS is composed of three critical words.

Geographic refers to a known location of a primary database comprising observations of features, activities, or events defined in space as points, lines, or areas, and assay value, in terms of geographic coordinates (latitude, longitude, and elevation). The measuring units are either in degrees/minutes/seconds or the Universal Transverse Mercator (UTM) system. The various types of data are captured under a database management system (DBMS) or a relational database management system (RDBMS) in different layers.

Information means that the data are processed within GIS using high-speed powerful software tools for analysis of spatial data to yield useful knowledge, to make maps into dynamic objects and models, or as output when required by the user.

System implies a group of interacting, interrelated, or interdependent functions to reach the objectives of different users.

The sequence of activities in the GIS function is:

1. Data collection: measurement aspects of geographic phenomena and processes.
2. Storing: measurement stored in a digital database to emphasize spatial themes, entities, and relationships.
3. Retrieving: operate to create more measurements and discover new relationships by integrating.
4. Transformation: convert new representations to conform to uniform frameworks of entities and relationships.
5. Processing: a system for capture, storage, retrieval, analysis, and display.
6. Modeling: a system to store and maneuver geographic information.
7. Display: maps and reports.

GIS is a knowledge-based organized assemblage of hardware, software, geographic data, and professionals that capture, store, update, maneuver, analyze, and display all forms of geographically referenced information (Bonham-Carter et al., 1995; Sarkar, 2003).

3.4.2 Components of Geographic Information System

The main components of GIS involve five subsystems:

1. Hardware.
2. Software.
3. Geographic reference database.
4. Method.
5. People: professionals (multiusers from the same database).

The hardware component of GIS is the main input/output system and consists of computers or a central processing unit (CPU) for the storage of data and software. A high-capacity disk drive of the CPU is the storage unit for data and programs. The digitizer and scanner are attached for converting maps and documents into digital form. The output units consist of a monitor for online display a plotter, and a printer to see results as hard copy prints of maps, images, and other documents. The temporary and permanent storage devices are pen drive, compact disk, magnetic tape, and external disk.

The software is the key subsystem that includes the programs and interface for driving the hardware. It is responsible for total data management, storing, analyzing, maneuvering, and displaying the data or geographical information. Efficient, quality software must be user-friendly, compatible, well documented, and cost effective. There is much commercial software available, which can be tailor-made for specific uses. Some of the popular names are ArcInfo, ArcView, MapInfo, etc.

The data, or more precisely georeferenced data, are the most significant component of the GIS system. Data can be purchased from a commercial data provider or collected in-house and compiled to custom specification. The key functionality of GIS is integration of spatial and tabular data stored in standard formats of DBMS, RDBMS, and Structured Query Language (SQL).

The right method is significant for successful operation of GIS technology. A well-designed implementation plan with decision support and business rules is unique to each organization.

GIS technology cannot be useful without competent people. Specialists design the total system for a wide range of end users. The users belong to multidisciplines, e.g., computer science, agriculture, forest, town planning, industry, geology, etc. Each one can share a common database and generate results as required by them. The identification of specialists and end users is significant for proper implementation of GIS technology.

GIS is generally considered to be expensive and difficult to use. However, with the advent of new technology like graphical user interface and powerful and affordable hardware and software it is gaining ground and included in the mainstream.

A complete flow diagram of the GIS system is given in Fig. 3.8.

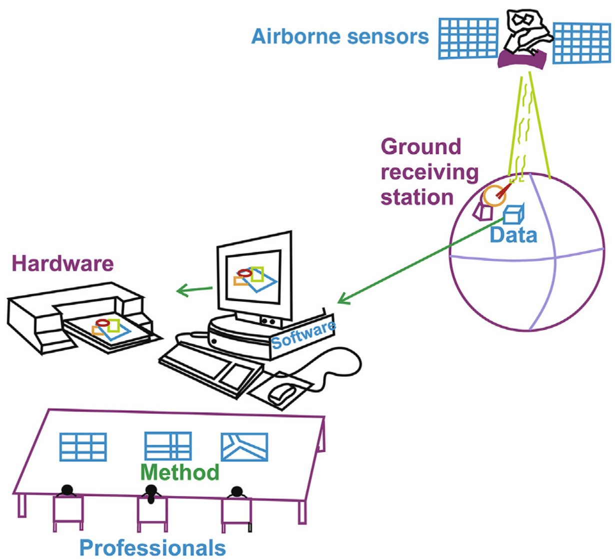

FIGURE 3.8 A typical functional aspect of geographical information system interfacing between major components from data collection to multiuser end results.

3.4.3 Capabilities

GIS has the capability of multiuser, multipurpose functions:

1. GIS is the high-tech equivalent of a quick and efficient map generator. It accesses and stores data in digital format and enables complex analysis and modeling.
2. It is capable of conducting the location analysis of various attributes stored at different layers, linking them to explain the causes and effects that yield results. The presence of surface weathering, topography, lithology, and structures at individual layers supported by geobotanical, geochemical, and geophysical evidences can lead to the discovery of massive hidden sulfide deposits/water bodies/oil and gas reservoirs.
3. It responds on query and displays results after satisfying certain spatial conditions. A well/drill site can be planned within a preset distance from a township by satisfying spatial conditions of possible aquifers, township, and existing pipeline.
4. It is capable of performing temporal analyses at time intervals over many years to derive relationships between changing land-use practices and future requirements.
5. It can evaluate different scenarios by applying sensitivity analysis and forecasting the best one. It can continuously monitor and revise decisions with changing assumptions and additional inputs.

3.4.4 Data Input

DBMS, RDBMS, and SQL software with error-checking facilities incorporate or import data from outside sources, and update and alter them if necessary. The data can be directly entered into the GIS platform manually or created outside in standard ASCII (American Standard Code for Information Interchange) files. GIS is also capable of importing data files that are created in other formats. GIS must provide the capability to export data to other systems in a common format (e.g., ASCII). Maneuvering the database to answer specific data-related questions is organized through a process known as database analysis. GIS must provide ways to modify, refine, revise, and update the database.

Two types of data are incorporated into GIS applications:

1. The first type consists of real-world phenomena and features that have some kind of spatial dimension such as a geological map (Fig. 3.9). These data elements are depicted mathematically in GIS as points, lines, or polygons that are referenced geographically or geocoded to some type of coordinate system. They are entered into GIS by devices like scanners, digitizers, Global Positioning System (GPS), air photographs, and satellite imagery.

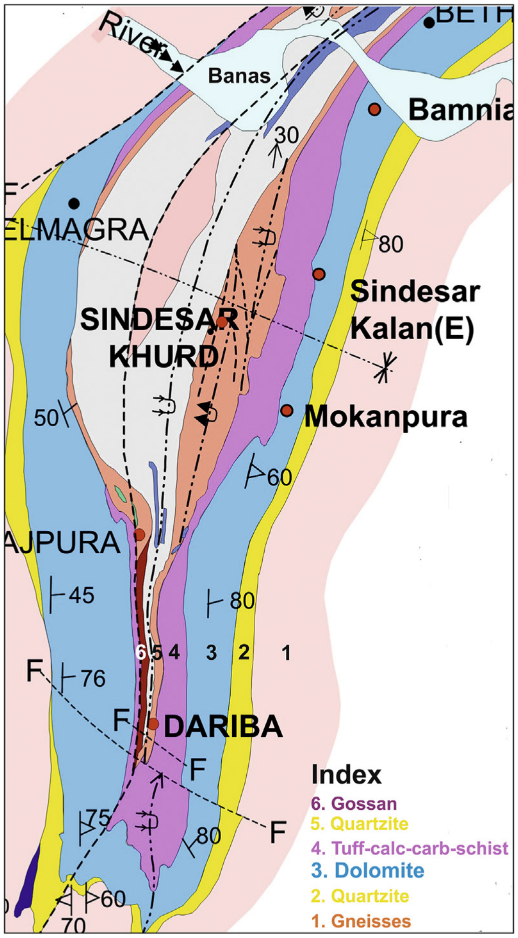

FIGURE 3.9 Data model of real-world phenomena and features having spatial dimension (e.g., geological map of Rajpura-Dariba base metal belt) usually incorporated into geographical information system (GIS) applications.

2. The second data type is often referred to as an attribute or point data such as soil profile. Attributes are pieces of data that are connected or related to the points, lines, and polygons mapped in GIS. This attribute data can be analyzed to determine patterns of importance. The attribute data are entered directly into a database where they are associated with element data. GIS uses one of the two primary types of spatial data, i.e., vector and raster, to represent the location component of the geographic information.

The vector data model is directional and represented by points, lines, and areas. Points are zero-dimensional objects (nodes) and represented by a single coordinate (x, y), e.g., sample, mine, house, city location. Lines are

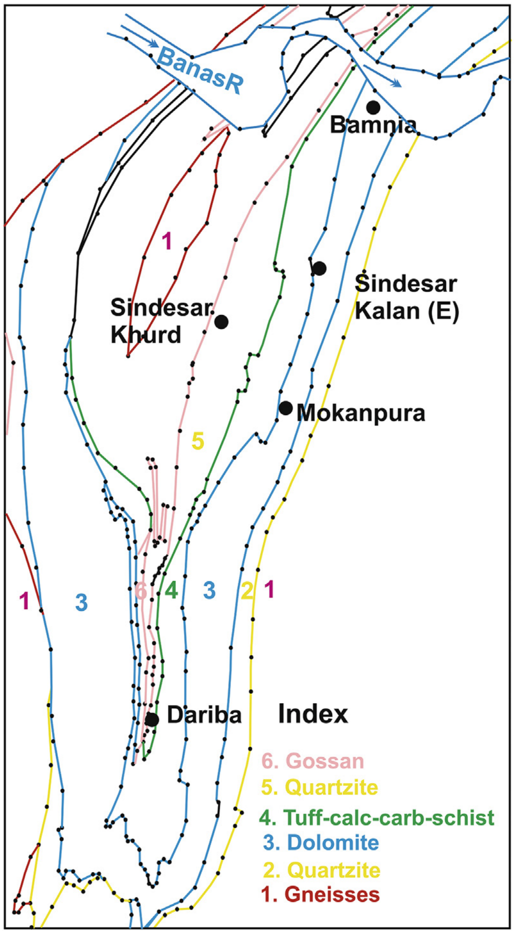

FIGURE 3.10 Data model by transformation of geographical phenomena of Rajpura-Dariba base metal belt into vector mode.

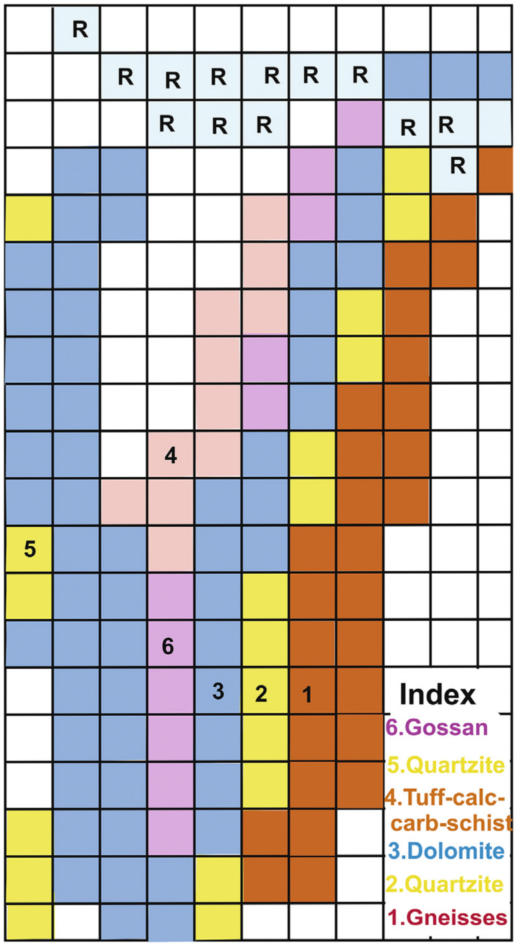

FIGURE 3.11 Data model by conversion of geological information of Rajpura-Dariba base metal belt to raster mode for geographical information system (GIS) applications in mineral exploration.

one-dimensional objects (line) and represented by a set of points or pair(s) of coordinates, e.g., roads, streams, faults, shears, lineaments, and drill hole paths. Polygons (2D areas representing dolomite or orebody) are bounded by a closed loop, joined by a set of line segments. 3D objects are embodied (x, y, z), where z is elevation, e.g., hills. The vector data model is particularly useful for representing discrete objects e.g., sample point, roads, streams, faults, and rock boundaries in the form of points, lines, and polygons, and stored as set of coordinates. The data in vector format are geometrically more precise and compact (Fig. 3.10).

The surface is divided into regular grids of cells represented by rows and columns or pixels of identical size and shape in the raster data model (Fig. 3.11). The location of geographic objects or conditions is defined by the coordinates of the cell position. Each cell indicates the type of object, class, category, measurement, condition, or an interpreted value that is found at that location over the entire cell. The smaller the cell size, the higher is the resolution with precision and detailed information. However, the data storage space will be enormous. On the contrary larger the cell size lesser data space will be required with approximate or less accurate information. In the case of a very coarse grid, several data types may occur in each cell, will be treated as homogeneous, and will generate inaccurate results during data analysis.

Merits and demerits between vector and raster data are modified after David (1997) and given in Table 3.3.

3.4.5 Projection and Registration

One often comes across maps of the same area containing different features (geology, geochemistry, and geophysics) and in different scale. GIS has the capability to maneuver the geocoded map information from different sources to common scale so that it can fit and register. Projection is a fundamental component of mapmaking in GIS. It is a mathematical function of transferring information from

TABLE 3.3 Salient Advantages and Disadvantages of Vector and Raster Data Models

Vector Data Model	Raster Data Model
Advantages	
Data storage at original georeferenced coordinates at higher spatial resolution, maintain and form without generalization	Geographic location of each cell is identified by its position in the cell matrix. Best resolution at smallest cell size
Graphic output is more accurate and realistic like cartographic representation	Data structure is simple and compact, storage in flat ASCII format for easy-to-use program and quick analysis
Most data, e.g., hard copy maps, are in vector form and no data conversion is required	Retrieval, updating, and generation of data. Grid-cell systems compatible with raster-based output devices—plotters and graphic terminals
Efficient encoding of topology and operations by network analysis	Topology can be completely described with network linkage
Data are less voluminous and technology is less expensive	Discrete data enable integrating two data types. Computational efficiency in overlay analysis
Disadvantages	
Location of each vertex needs to be stored unambiguously	Cell size decides resolution. The smaller the cell size, the more complex the data structure and the more expensive is the technology
Vector data conversion to topological structure is processing intensive and requires extensive data cleaning	Difficult to adequately represent linear features depending on the cell resolution. Network linkages are difficult to establish
Algorithms for analysis functions are complex, inherently limiting functionality for large data	Processing of associated attribute data is complex with a large volume of data
Elevation data are not effectively represented in vector form. Often require sizeable data generalization or interpolation of data layers	Most input data are in vector form and need conversion from vector to raster by escalating processing, generalization, and unsuitable cell size
Spatial analysis and filtering within polygons is not possible	Most output maps from grid-cell systems do not conform to high-quality cartographic needs

a 3D surface to fit in a 2D medium. The digital data may have to undergo other transformations like projection and coordinate conversions to integrate them into a GIS before they can be analyzed. This process inevitably distorts at least one of the following properties: shape, area, distance, or direction. Different projections are used for different types of map for specific uses. GIS has the processing power to transform digital information gathered from sources (digitized data, aerial photographs, satellite, and GPS) with different projections to a common frame.

3.4.6 Topology Building

Topology defines the mathematical representation of the spatial relationship between geographical features. It describes the relationships between connecting or adjacent coverage attributes. Topological relationships are built from simple elements into complex elements such as points (simplest elements), arcs (sets of connected points), and areas (sets of connected arcs). Three types of relationship exist in topology: connectivity, area definition, and contiguity. Storing connectivity makes coverage useful for modeling and tracing in linear networks. Storing information about area definition and contiguity makes it possible to merge adjacent polygons and to combine geographical features from different coverages with overlay operations.

3.4.7 Overlay Data Analysis and Modeling

Overlay analysis or spatial data analysis is a function in GIS applications to spatially analyze and interpolate multiple types of data streaming from a range of sources. Each type of data pertaining to the same area or similar objects is registered in vector or raster mode in individual files. New information can be created by overlaying or stacking (Fig. 3.12) of the related layers with common georeferences and analyzing through the GIS function. There are several different spatial overlays and manipulation operations to arrive at a specific model, which can be used on features of the user's interest.

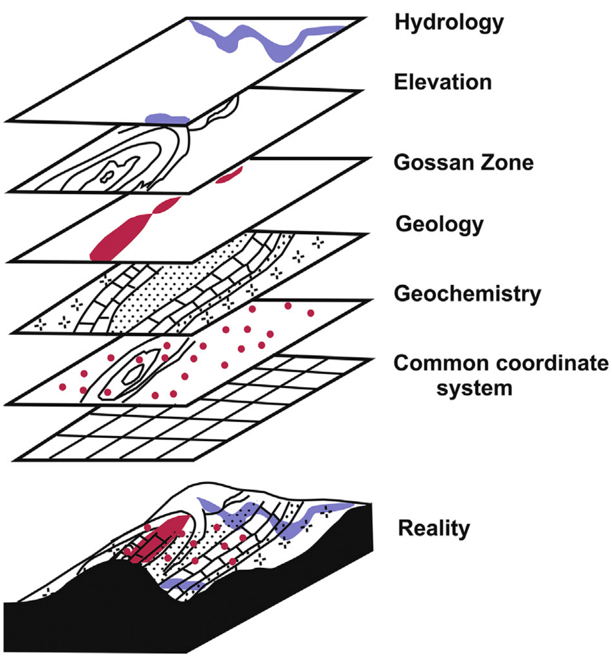

FIGURE 3.12 Concept of overlay analysis and integration of multilayer data of Rajpura-Dariba base metal belt for identifying drill targets: an example of geographical information system (GIS) application in mineral exploration.

3.4.7.1 Digital Evaluation Model, Digital Terrain Model, Terrain Evaluation Model, and Triangulated Irregular Network Model

The **digital evaluation model** (DEM) is a 3D representation of a surface topography using a raster or vector data structure. Any digital representation of a continuous surface of relief over space is known as DEM. It describes the elevation of any point in a given area in digital format. The **digital terrain model** or **terrain evaluation model** exhibits 3D spatial distribution of terrain attributes. It is a topographic map in digital format, consisting not only of a DEM but also types of land use, settlements, drainage, road networks and related features. The **triangulated irregular network** is a 3D surface model derived from irregularly spaced points and break line features. The basic unit is a triangle consisting of three lines connecting three nodes. Each triangle will have three neighbors except the outer periphery. Each node has an x, y coordinate and a z value or surface value. These models are created by digitizing contour maps along with point, line, and polygon data of related objects followed by vector-to-raster conversion and interpolation to derive the desired results. These are useful for road and rail line and dam site planning, reservoir capacity estimation, identifying ridge lines and valleys, visibility studies, and cut and filling problems.

3.4.7.2 Mineral Exploration Model

Overlay analysis is useful in mineral exploration for identifying targets. The example in Fig. 3.9 contains conceptual data from a range of source maps of Rajpura-Dariba base metal belt, Rajasthan, India. The files contain hydrology, elevation, surface signature, geology, and geochemistry. All source data have been geocoded and registered on a cell-by-cell basis from a series of land data files in individual layers. The analyst module of GIS manipulates and overlays simultaneously the information derived from various data files. The analyst uses the system to interrelate the geocoded source data files. The interpreted result is expected to define the target area for exploration of possible sulfide deposits. The example is a concept-based model attempting to generate thematic maps. The addition of remote sensing electromagnetic data and surface geophysics will certainly strengthen the model to forecast exploration targets.

3.4.8 Geographic Information System Application in Mineral Exploration

The applications of GIS in mineral exploration are widely used internationally. The GIS platform allows establishing a mineral deposit database for a region or country by integration of all available geoscientific data (even dissimilar) into a digital single and unified database. The recommended approach is to compile all of the available geoscientific data within GIS in the context of an exploration model. It will produce a brief report and mineral potential maps of a province, region, district, belt, deposit, and block. Careful consideration must be given to developing the model so that all of the relevant aspects of the deposit being sought are represented. The model is important in deciding the logical weight to apply by a geologist having adequate knowledge of the model and the deposit related to each of these aspects. The final map indicates the ranks and priority for exploration targets in the study area.

An extension of the GIS database is incorporation of exploration data consisting of deposit name, location, infrastructure available, parks and reserve forests, historic and current exploration details, drill hole location, summary logs, drill sample assay value, geochemistry, electromagnetic and gravity images, mineral occurrences, reserve and resource detail, and lease status like reconnaissance permit/prospecting license/mining lease. This mineral resource information system acts as an exploration guide to new targets and decision bases for free areas. It will be in SQL base system so that investors can design their objectives and search online for desired results.

3.5 GLOBAL POSITIONING SYSTEM

GPS is a universal satellite-based navigation system developed, replaced, monitored, and maintained by the US Department of Defense originally for military applications. Its official name was Navigation Satellite Timing and Ranging. The first global positioning space vehicle was launched in 1978. Total network satellite launching was completed in 1994 and the system became fully operational in 1995. Since then the system has been available for civilian use and works worldwide under any weather conditions, 24 h a day without paying any routine subscription or setup charges. The total number of satellites in the constellation today is 60 (16 for civilian use and the remaining for military use and spares). A GPS satellite weighs about 1000 kg. Precision for civilian use is in the centimeter scale and that for military purposes is in the millimeter scale. GPS consists of three major segments (Fig. 3.13). These are space segment, ground control segment, and user segment.

3.5.1 Space Segment

The space segment originally comprised 24 orbiting satellites (21 active and 3 spares), in six circular orbital planes with four satellites in each plane. The orbital planes are centered on Earth and have 55 degrees inclination relative to Earth's equatorial plane. The planes are equally spaced, separated 60 degrees apart along the equator from a reference point to the orbit's intersection. The satellites are orbiting at an altitude of approximately 20,200 km. Each satellite makes two complete orbits each day, i.e., a complete rotation around Earth in 12 h. The orbits are so arranged that at least six satellites are always within line of sight from almost anywhere on Earth's surface.

3.5.2 Ground Control Segment

The flight paths of the satellites are tracked by the ground control segment located at various monitoring stations of respective participative countries. In the event of any deviation of the space vehicle from its designed orbit the ground control station transmits the tracking information to the master control station. The master control station in turn uploads orbital and clock data to each GPS satellite regularly with a navigational update using ground antennas. These updates synchronize the atomic clocks on board the satellites within a few nanoseconds of each other.

3.5.3 User Segment

The user segment uses various types of receivers to compute the coordinates (X, Y), elevation (Z), velocity, and time estimates. GPS receivers are composed of an antenna tuned to the frequencies transmitted by the satellites, receiver-processors, and a highly stable atomic clock. The receiver computes its position and time by making simultaneous measurements to a number of satellites. A 2D position, i.e., latitude and longitude, can be computed by the signals of three satellites. Signals from at least four satellites are required for determination of 3D location, including elevation and clock bias. The receiver displays information comprised of a number of visible satellites, location, and speed to the user. The location works on both

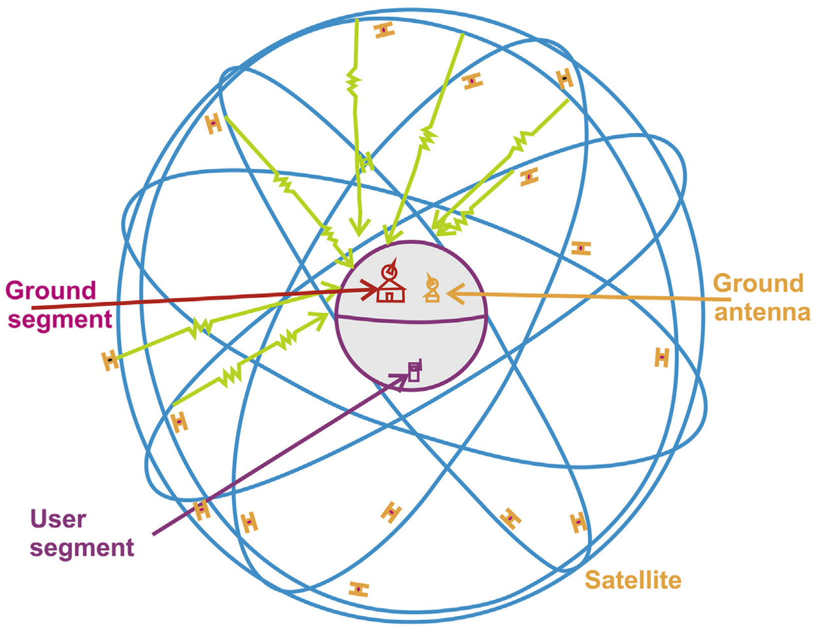

FIGURE 3.13 Conceptual overview of constellation of Global Positioning System (GPS) satellites in space, ground control, and user segments.

longitude and latitude, i.e., degrees/minutes/seconds, and UTM in a metric grid system. There are 60 zones to cover the entire Earth's surface. The receivers can include an input for differential corrections and relay position data to a computer. They can interface with other devices using different methods, including a serial connection, USB, or Bluetooth.

3.5.4 Signals

GPS satellites transmit low-power time-coded radio signals of 1575.42 MHz frequency in the UHF band. Signals travel by line of sight through semitransparent medium, but not through solids, metals, and electromagnetic fields, and are recorded by ground GPS receivers. The sources of error and interference of signal transmission include ionosphere and troposphere delay, signal multipath, clock, orbital, number of visible satellites, satellite geometry and shading, and international degradation of signals.

3.5.5 Types of Global Positioning System

The types of GPS receiver can be broadly classified on the basis of accuracy required and associated cost of the unit.

3.5.5.1 Handheld Global Positioning System

The handheld GPS is the simplest, cheapest, and easiest unit, consisting of a single receiver (Fig. 3.14). The technology is simple and reasonably accurate. The location position, computed from the signals, can be distorted by 10–30 m. Most mobile cell phones provide the name of locations and road maps, and show directions to destinations with precise distances in meters while traveling by receiving signals from local antenna.

3.5.5.2 Differential Code Phase Global Positioning System

GPS measurements are prone to multiple errors on account of uncertainties in satellite ephemeris, atmospheric condition, quality of receiver, and multipath situation. The differential GPS works on simultaneous measurements by receivers at a reference station with precisely known location, clock time, and number of roving receivers moving from point to point. The positional introduced noises measured at the base station are used to compensate instantly the position measured by the rovers to attain greater accuracy. The base station may be a ground base facility or a geosynchronous satellite. In either case, the base station is known with precise location value. This known value can be compared with the signals received from GPS satellites and thus can find the international error introduced by each GPS signal. The correction can be immediately transmitted to the mobile GPS receivers

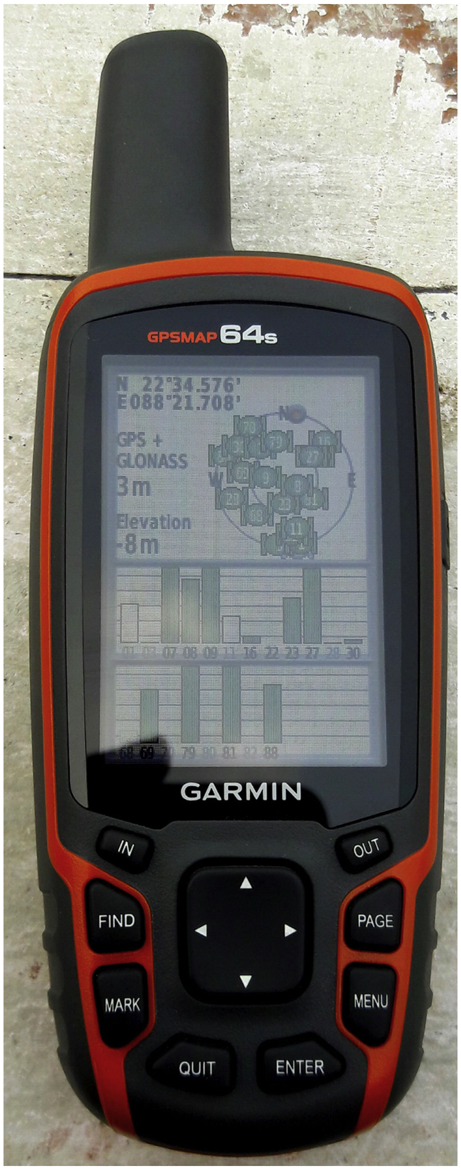

FIGURE 3.14 Hand-held Geographical Positioning System (GARMIN GPSMAP 64s) capable of measuring 3D coordinate system and trace the traverse path, rock contacts, structural features, and many more. *Courtesy Prof. Sayad Rahaman.*

(real-time Differential Global Positioning System [DGPS]) to compute a much more accurate position. The receiver position can also be corrected at a later time during processing by GPS software. The use of DGPS can greatly increase positional accuracy within 1 m.

3.5.5.3 Carrier Phase Tracking Global Positioning System

Carrier phase tracking GPS signals have resulted in the development of land surveying, geological mapping, and as a guide to reach the target destination. The positions can be measured up to a distance of 30 km from a reference location without any intermediate point. A small handheld unit allows positions and traverse routes to be downloaded to GIS software for geological mapping. A small unit can store more than 300 sample positions and tens of routes.

3.5.5.4 Electronic Total Station

An electronic total station (ETS) is an electronic/optical instrument used in modern all-purpose surveying. The total station is an electronic theodolite (total station theodolite) integrated with an electronic distance meter to read slope distances from the instrument to a particular spatial entity. Some models include internal electronic data storage to record surveyed points (x—northing, y—easting, and z—elevation), distance and horizontal and vertical angles. The data can be downloaded from the total station to a computer. The application software is used to process results and generate maps of the surveyed area.

A total station is used to record the absolute location, geological contacts (maps), results of geological, geochemical, and geophysical surveys, borehole program, and even underground working layouts and stopes. The recorded data are downloaded onto a computer, processed and compared to the designed layout. Control survey stations at regular intervals are installed underground to facilitate survey by ETS.

3.5.6 Global Positioning System Applications

GPS systems are versatile and widely used for military and civilian purposes, including mineral exploration. The common uses are:

1. GPS systems operate both for airborne, and ground base.
2. Applications in ground-based mineral exploration include vehicle and route tracking, instant and precise location (latitude, longitude, and altitude) on land and sea during field traverses, geological mapping, and checking litho contacts, structures, surface samples, and borehole collar location. GPS provides precise time references, including the scientific study of earthquakes and as a required time synchronization method for cellular network protocols.
3. Civilian uses are land surveying, land-use pattern, forest mapping, drainage, helping farmers harvest their fields, and a time synchronization method for cellular network protocols. The areas of interests are weather forecasting, aviation, and road/rail/shipping transport.
4. The military applications of GPS have many purposes like reconnaissance and route map creation, navigation of soldiers to locate them in darkness or in unfamiliar territory, and to coordinate the movement of troops and supplies. GPS helps in missile and projectile guidance for accurate targeting of various military weapons. GPS satellites also carry a set of nuclear detonation detectors consisting of an optical, X-ray, and electromagnetic pulse sensor. This forms a major portion of the US Nuclear Detonation Detection System.

3.6 SOFTWARE IN REMOTE SENSING GEOGRAPHICAL INFORMATION SYSTEM

RS-GIS technology captures basic electromagnetic radiance data of 3D georeferenced satellite images in WGS84 UTM 36N and 37N coordinates. These coordinates and attributes include multidisciplinary activities by multiend users. The data input is in RDBMS/DBMS format for combined procession by commercial software to generate 2D/3D models and hard copies.

The software modules represent total interface system, and are responsible for generating, storing, analyzing, maneuvering, and displaying results. The strength of the software is to maintain user friendliness, compatibilities, documentation, and to be cost effective. Mineral exploration and mining companies use RS-GIS to identify prospective areas for exploration, 3D orebody models, mining, infrastructure layout, and environmental management. Exploration and mining continues with estimation of reserves and resources with precision. The progress of GIS into three dimensions is a revolutionary change for the utility of technology in mineral exploration.

Available commercial GIS software is listed without any discrimination of superiority.

3.6.1 ArcGIS

ArcGIS is a group of GIS software developed by the Environmental Systems Research Institutes. It has two main modules: ArcInfo (Arc and Info) and MapInfo (Map and Info). Arc/Map means graphical entities and Info means attributes.

ArcGIS is a high-performance, dynamic software family that produces significantly better-looking accurate maps in the shortest time. It provides a review and responds to errors. It can preview documents, estimate rendering time, save to a map service definition format, and combine layers (referencing feature or raster data) into a single layer package comprising both layer file and data. It has the facility to share layers with itself and global groups via online ArcGIS or email. The main components of ArcGIS are ArcInfo, ArcView, and ArcReader.

ArcInfo is a comprehensive GIS within the ArcGIS family. It also adds advanced geoprocessing and data conversion functionality. ArcInfo builds and manages a complete intelligent GIS, including maps, data, metadata, geo-datasets, and workflow models. The key features include advanced spatial analysis, extensive database, multiuser editing, and high-end cartography in an exploration program.

ArcView is a fully featured GIS for visualizing, analyzing, and creating data with a geographic component. It consists of address, postcode, GPS location, city, local government area, etc. ArcView visualizes, explores, and analyses data, revealing patterns, relationships, and trends.

ArcReader is a simple desktop mapping application. It allows the viewing, exploring, and printing of maps, and possesses interactive mapping capabilities by accessing a wide variety of dynamic geographic information and viewing high-quality maps.

3.6.2 AutoCAD

AutoCAD Map, patented by Autodesk, is a powerful drafting tool used widely for engineering drawings with accuracy and 3D viewing. It works on 2D and 3D coordinate systems. It is user-friendly and available at a reasonable cost. It is extensively used by geologists for the preparation of maps, subsurface plans, and sections for estimation of resources and reserves by conventional methods.

3.6.3 IDRISI

IDRISI is an integrated GIS and image processing software solution developed by Clark Labs. It provides many modules for the analysis and display of digital spatial information. Land Change Modular provides land cover change analysis and prediction with tools to analyze, measure, and project the impacts of changes on habitat and biodiversity. It involves a set of feasible alternatives for multiple criteria group decision-making problems.

3.6.4 Integrated Land and Water Information System

Integrated Land and Water Information System (ILWIS) is developed by the International Institute for Aerospace Survey and Earth Sciences in the Netherlands. It is RS-GIS software for both vector and raster processing. The main features include digitizing, editing, analysis, and display of data, as well as production of quality maps.

3.6.5 MapInfo

MapInfo, developed by MapInfo Corporation, is a natural resources solution for mineral exploration, mining, engineering, infrastructure, and environment. MapInfo Vertical Mapper module has a wide range of analysis tools to reveal trends in datasets. It has unique prediction capabilities to specify a test location and identify areas with statistically similar attributes. The software executes 3D orebody modeling and estimation by all standard interpolation principles from existing point files or tables, regardless of data type. It performs triangulated irregular network with smoothing, inverse-weighted distance function, natural neighbor and rectangular (bilinear) interpolation, kriging, and custom point estimation. The advance module includes modeling options by overlaying multiple layers and applying a mathematical function, calculating steepness of slopes or the direction the slopes are facing in a grid, showing cross-sections, and displaying a 3D perspective view of the terrain with optional overlay of imagery and natural neighbor analysis.

3.6.6 Micro Station

Micro Station, developed by Bentley Systems, is an easy to access, powerful, and interoperable 3D CAD software platform for design, construction, operation, and dynamic viewing.

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