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GPR APPLICATIONS IN LIMNOLOGY

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ABSTRACT

Ground Penetrating Radar (GPR) is a geophysical technique that is widely used to study the shallow subsurface in a broad range of applications and environmental settings. It can provide relatively high-resolution, near-continuous shallow subsurface images. Many workers all over the world have conducted GPR study. Study has been done in various environments as GPR has a wide range of applications. Lake study using GPR application has been utilized by many workers. Though GPR study has also been done in India, the application of GPR in limnology is still in its infancy. Works carried out in lake using GPR is really a very challenging task. However, the utility of GPR is quite interesting in imaging the lake bottom, which highlights the environmental history of the lake as well as their origin. It is well-suited for mapping the thickness and character of sediments beneath lakes. Its noninvasive capabilities make GPR an attractive alternative to the traditional methods used for subsurface characterization.

Keywords: Ground Penetrating Radar, limnology, lake, sediment,

INTRODUCTION

The most important part for many limnological studies is a bathymetric map and an estimation of the distribution, thickness, and stratigraphy of the sediments underlying the lake. This aids in locating the coring sites and further helps in conducting the overall basin analysis. GPR techniques are utilized as it is well-suited for mapping the thickness and character of sediments beneath lakes. It produces a continuous cross-section of the lake bottom and the underlying sediment column. It also can effectively see several meters through materials deposited on the lake bottom and can reveal different layering, reflectivity of underlying material.

GPR transmits pulses of radio frequency energy waves into the subsurface, and reflections from heterogeneities in the sediment are returned to a receiver. In this way, a radar image of the sediments beneath the lake can be produced and used to interpret the structure and extent of subsurface deposits (Fig.1).

Fig.1: GPR equipments (Mala Geosciences).

GPR is one of a number of remote sensing geophysical methods to study the subsurface environment. GPR is a quick, nondestructive environmentally safe technique for near-surface underground exploration. It has many applications, including groundwater and mineral exploration, archaeological and forensic investigations and depth soundings through ice or water. It is a non-invasive, portable device that can provide relatively high-resolution, near-continuous shallow subsurface profiles. GPR is a geophysical technique that is widely used to study the shallow subsurface in a broad range of applications and environmental settings. GPR measures changes in the electromagnetic properties of subsurface features that cause reflection of transmitted electromagnetic waves (Van Dam, 2001).

GPR operates in the same manner as navigational radar systems, in that it sends pulses of electromagnetic (EM) radar waves into the ground in order to identify the shapes, sizes and locations of subsurface features. GPR uses an electromagnetic pulse and is sensitive to variations in electrical properties. GPR system consists of a transmitter that emits high frequency electromagnetic waves into the subsurface and receivers to record energy reflected from interfaces across which physical properties change (Fig.2). These physical properties are related to sediment composition and water content within the sediment. Factors that affect the maximum depth of penetration include the material type that the signal penetrates, the conductivity of the overlying material, and the frequency of the antenna used (Reynolds, 1997; Tang, 2004). Highly conductive materials will scatter the EM signal and decrease the maximum depth of penetration. When the transmitted EM wave encounter changes in subsurface materials, the properties of the wave are altered, and part of the wave is reflected back to the surface, where data on its amplitude, wavelength, and two-way travel time are collected for analysis.

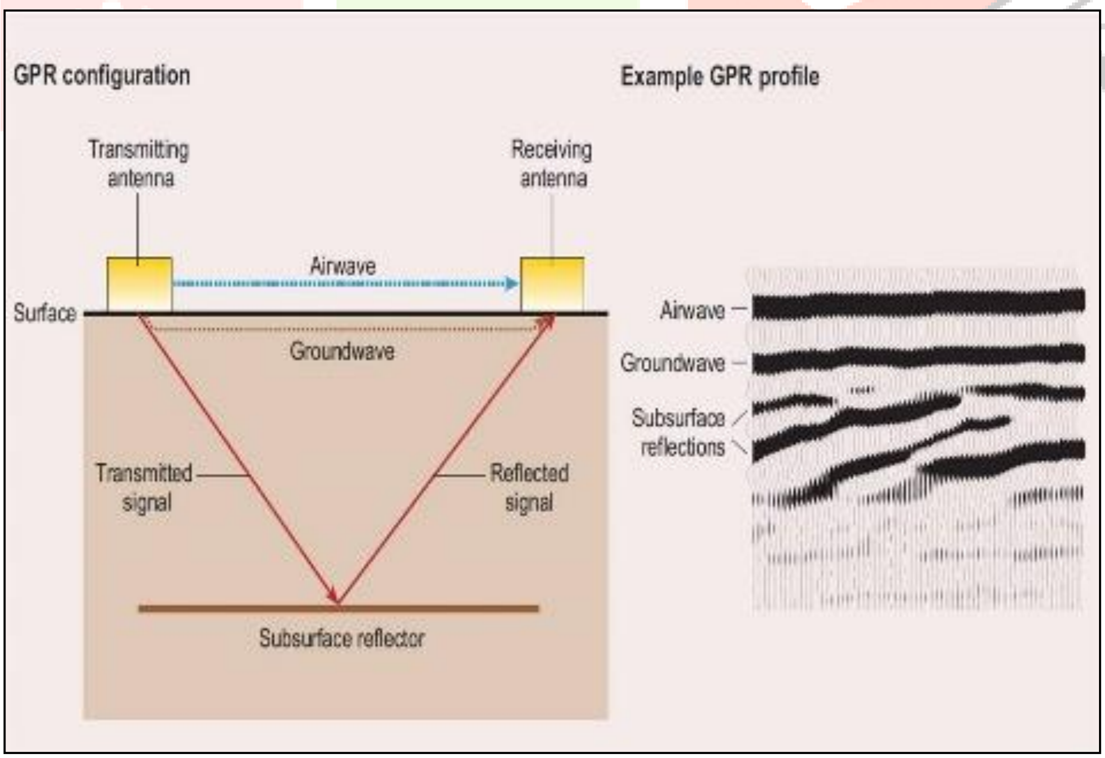

Fig.2: Ray paths for the airwave, groundwave and reflected wave and example of resultant GPR profile (after Neal, 2004).

GPR STUDY IN INDIA

Shukla et al. (2008) studied the shallow subsurface sedimentary architecture of Modwa spit, Gulf of Kachchh using the application of GPR. GPR survey delineated a variety of the radar surfaces and radar facies which reflects not only large scale sedimentary architecture, but depositional facies of the beach ridge complex. Trivedi et al. (2012) interpreted the dune genesis from sedimentogical data and GPR signatures from Ashirmata dune field, Mandvi beach, Gujarat.

Glacier depth and moraine cover is estimated using GPR at Patseo and Samudratapu glaciers in Himachal Pradesh in Western Himalayas (Singh et al., 2010). Singh et al. (2012) also carried out GPR survey to estimate the ice thickness at Chhota Shigri glacier in Himachal Pradesh. The bedrock reflection is distinctly observed in the profiles indicating ice thickness varying from 110 to 150 m with approximately 0.049 km^3 water equivalent for the surveyed area. The results also showed subsurface features like point reflector and a linear non-bed reflection within the ablation ice zone. Sridhar and Patidar (2005) also studied a point-bar in the Mahi river basin, Gujarat using GPR.

Chanu et al (2013) profiled the sub-bottom of Punem Lake along with the bathymetric mapping using GPR. Deep horizontal continuous line, hyperbolic curve and shallow chaotic reflection are the primary features imaged by GPR (Fig.3). Facies observed in GPR profiles (Fig.4) shows high amplitude non-parallel reflections dominating above low amplitude parallel lines. Such type of reflection pattern in Punem Lake sediment is interpreted as lacustrine sediment covering the older surface and this interpretation correlates with the core samples which is also similar to the work done by Moorman (2001) in paleo-limnological studies (Fig.5).

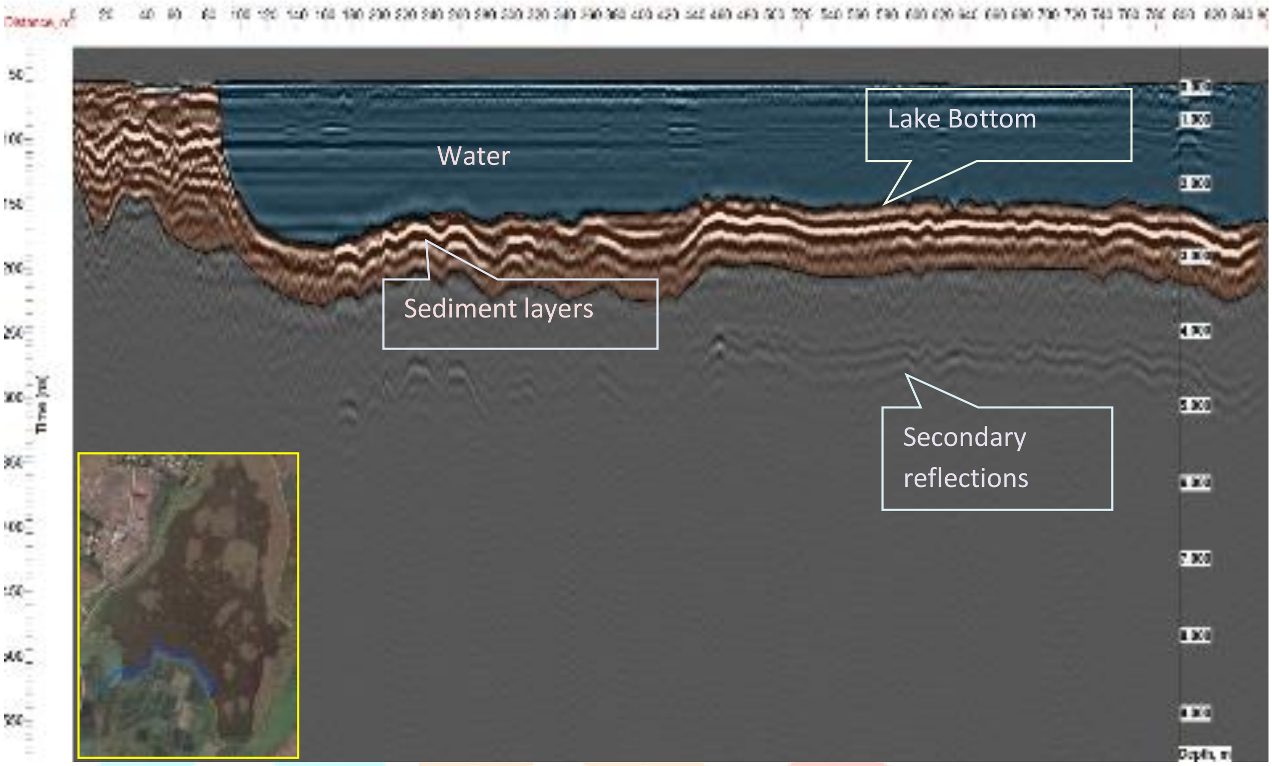

Fig.3: Interpreted GPR profile across Punem Lake. Picture in the inset shows the GPR transect in blue line when loaded in Google earth.

C… ers have done GPR study in various fields. But lake study using GPR is still a new field in India and is indeed a very challenging research.

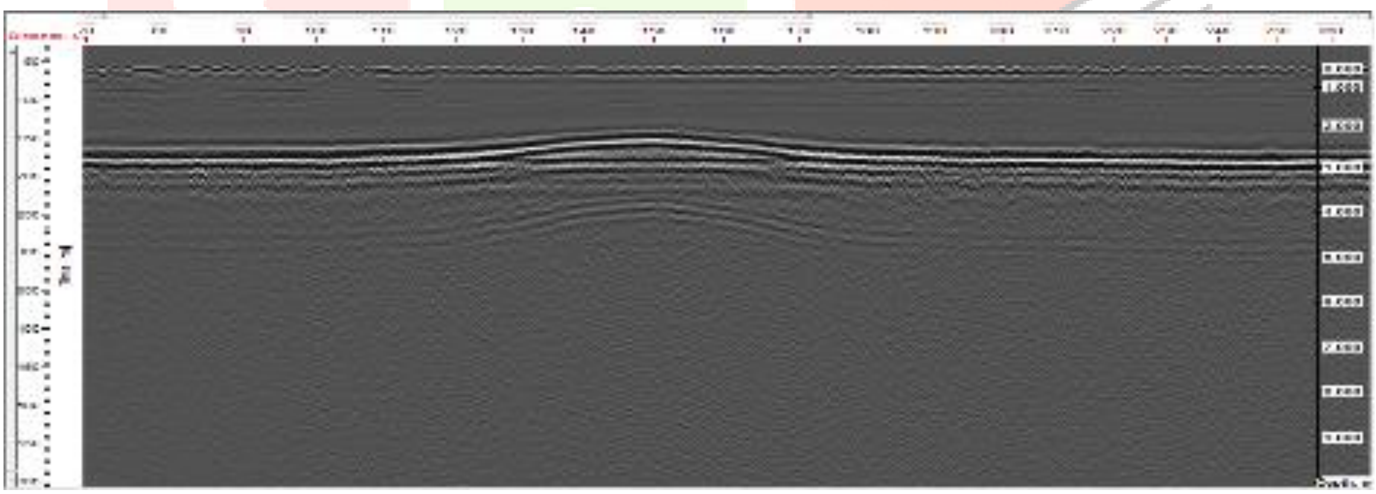

Fig.4: Section of GPR profile showing lacustrine sediment covering the older surface

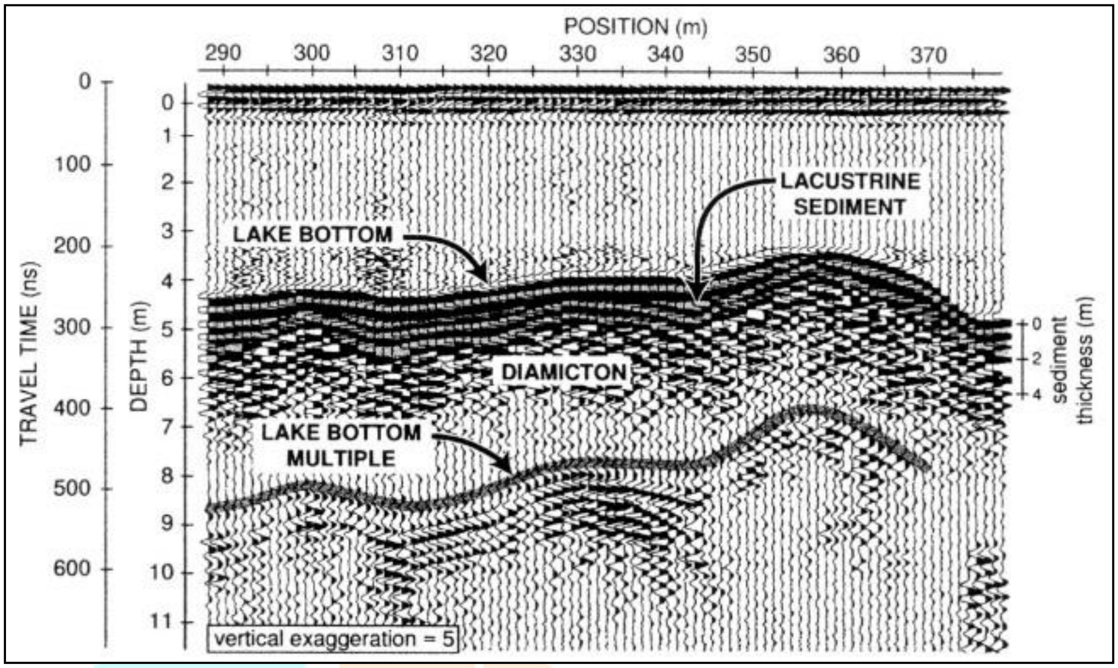

Fig.5: Example of lake bottom multiple reflection (after Moorman, 2001)

GPR STUDY IN INTERNATIONAL SCENARIO

Moorman, 2001 studied the application of GPR in paleolimnology. He has also delineated lake bottoms as deep as 25 m with a 25 MHz antenna. GPR aids in locating coring sites and conducting the overall basin analysis of lake. Sellmann et al. (1992) also surveyed the sub bottom of lake using GPR. Although fresh water has relatively low attenuation, the presence of suspended sediments in the water will increase attenuation, causing a reduction in depth penetration. From a boat, GPR is effective in water depths upto 30 m and Lake Bottom sediment thicknesses of over 6 m are delineated. It is also discovered that GPR could be used for bathymetry mapping when weed growth prevented acoustic profiling (Kovacs, 1991). Bathymetric maps and sediment morphology of ice-covered lakes have been done as well. Moorman and Michel (1997) imaged through ice covered Arctic lakes with water depths up to 19 m with a 100 MHz antenna.

Lake study using GPR has been done by many other workers (Mellett, 1995; Jol et al, 1996; Pipan et al, 1999; Last and Smol, 2001(vol.1); Jol et al, 2003; Kruse and Ed, 2003; Wilkins and Clement, 2007; Banks and Johnson, 2011; Cedrone, 2012; McCary, 2012). Some other case histories that describe the use of GPR on water bodies include Wright et al. (1984); Haeni, et al. (1987); Beres and Haeni (1991); Ayotte (1994) and Haeni (1996). Its applications range from determining the stratigraphy of peat in wetlands (Theimer et al., 1994), defining the boundaries between peat and organic-rich lake sediment (Hanninen, 1992; Slater and Reeve, 2002), and estimating peat reserves (Warner et al., 1990). The environmental studies using GPR has also been carried out by various workers like Grant et al 1996; Schenk et al 1993; Van Heteren et al (1996) etc. The above studies reveal that a clear understanding of the underlying bottom layers of soil, water, wetlands etc is very essential as it provide various useful information that aids in studying and examining the diverse fields of the environment. A lot of research work has been reported for mapping the distribution and thickness of lacustrine sediments (Delaney 1992; Moorman and Michel, 1997). Smith and Jol (1992 and 1997) have undertaken extensive work on mapping the structure of modern and ancient deltaic deposits.

In temperate areas GPR has been tested for studying bottom deposits (Arcone et al., 2006; Buynevich and Fitzgerald, 2003; Fuchs et al., 2004; Sambuelli et al., 2009; mapping bathymetry (Powers et al., 1999). Davis and Annan (1989) show an example of bedrock mapping beneath an ice-covered lake. They used an input frequency of 12.5 MHz and a station interval of 2 m and achieved resolution to about 20 m.

Recently, the quantitative approaches for the discrimination of sediment type using the amplitude of the GPR signal reflected from the water bottom have been carried out (Lin et al., 2010). Estimating the bathymetry and discriminating sediment types by analyzing the time delay and amplitude of reflections are mainly assumed in homogeneous medium of lake water. This assumption is valid in shallow rivers or lakes where there is little or no thermocline and therefore no reflectors before the bottom, but must be questioned for deeper lakes (Bradford et al., 2007).

Monitoring river erosion, lake filling and understanding the connection between surface water and underground water are critical environmental issues. Moorman and Michel (1997) imaged through ice covered Arctic lakes with water depths up to 19 m with a 100 MHz antenna and Moorman has delineated lake bottoms as deep as 25 m with a 25 MHz antenna (Moorman, pers. comm.). Bathymetric maps and sediment morphology of ice-covered lakes (Moorman and Michel, 1997) have been reported as well. Although fresh water has relatively low attenuation, the presence of suspended sediments in the water will increase attenuation, causing a reduction in depth penetration. From a boat, GPR was effective in water depths upto 30m and lake bottom sediment thicknesses of over 6m were delineated. It was also discovered that GPR could be used for bathymetry mapping when weed growth prevented acoustic profiling (Kovacs, 1991). Lake study using GPR has been done by many other workers (Jol and Lawton, 1996; Pipan et al, 1999; Wilkins and Clement, 2007; Last W. M. &. Smol J. P, 2001; Jol and Lawton, 2003; Kruse, 2003; Mellett, 1995). Moorman and Michel (1997) effectively used GPR in water depths upto 30m and lake bottom sediment thicknesses of over 6m were delineated.

The use of GPR in sedimentological research is one of the recent developments. It is generally understood that water plays a crucial role in the behaviour of GPR waves (Davis and Annan, 1989). GPR measures changes in the electromagnetic properties of sediments that cause reflection of electromagnetic energy. These changes in electromagnetic properties result primarily from changes in water content, governed in turn by grain-size and porosity (Topp et al., 1980). Most work with GPR has focused either on geological and sedimentological reconnaissance (Jol and Smith, 1991; Jol and Smith, 1992; Beres et al., 1995; Van Overmeeren, 1998; Neal and Roberts, 2000; Bristow and Jol, 2003; Jol and Bristow, 2003 and Neal, 2004). In sedimentary environments, variations in textural characteristics commonly cause the necessary changes in water content that trigger radar-wave reflections (e.g., Hanninen, 1992; Huggenberger, 1993). Sedimentological studies, especially on the texture of lake sediments, have been successful in reconstructing lake-level fluctuations in small temperate zone lakes (Digerfeldt, 1986; Saarse and Harrison, 1992; Dearing, 1997; Punning et al., 2005a, b).

CONCLUSION

GPR is a high resolution geophysical technique that can provide remarkable images of the subsurface of the earth. A GPR image represents the interaction between electromagnetic waves and the dielectric properties of the earth. It is deciphering the link between the resulting radar image and the subsurface properties and processes of interest that underlies the future usefulness of GPR for applications in lake study.

GPR is a valuable tool in limnological investigation as the bathymetry and the lake bottom sediment distribution, thickness and structure can be mapped easily. It can be towed behind a boat and enables even faster data collection. Bathymetry of lakes and several metres of sediments can be mapped beneath lakes with GPR. In the future it is anticipated that there will be immense development in limnological research as GPR systems performances continue to improve.

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