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HISTORICAL NOTE

Hundred years of geophysics (1834–1933)

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Abstract
Geophysics is relatively a new discipline in comparison to physics or geology. Contrary to general perception as an ancillary to geology, the discipline has been developed with a distinct focus of using the principles and methods of physics for the earth processes. Geophysics was born in the nineteenth century as a necessary element of theoretical geography. Academicians and researchers in the field of geography played chief roles from its birth to its present level of maturity. Historical scholarship in this paper provides an account of the development of the discipline over hundred years from its inception in the early nineteenth century. The article covers, how the discipline was conceptualised and what necessary steps were taken, such as establishing learned societies, publishing technical journals and text books, endowing university chairs, opening up departments and course curriculum, and most importantly, appearing as a primary discipline to cater to exploration for mineral resources.

Keywords Birth of geophysics · Courses · Journals · Learned societies

> Just as physics is not a list of facts about the world, history is not a list of names and dates. It is a way of thinking that can be powerful and illuminating (Matt Stanley, 2016)

1 Introduction

Now being the 20s of twenty first century, one would perceive that the discipline 'Geophysics' has emerged as a new avatar whose influence becomes conspicuous in prospecting mineral resources, mitigating environmental hazard, conducting geotechnical investigations and many more. Nevertheless, the discipline still remains a niche subject and except the professionals in the field, very few are well aware of the presence of the subject, let alone know its background of emergence as a new discipline. Many young beautiful minds before committing to the discipline of geophysics as their major career path often bear an impression, after going through web portals of various universities, that it is a branch of physics with a considerable dose of geology. Their impression is not quite wrong, but they would perhaps be surprised to know that the discipline was proposed, including the appropriate coinage 'geophysics' neither by geologists, nor by physicists but by geographers. Such an interesting fact on the birth of the new discipline in science will be discussed here.

The literature on the history of geophysics is very limited. Two important publications in the late 70s of twentieth century are worth mentioning. Those are: (i) a book on 'History of earth sciences' by Donald Herbert Hall (1925–2012) covering a brief glimpse of geophysics under the guise of 'Emphasis on physical geosciences' (Hall, 1976), but the historical background covered is not sufficient enough, and (ii) a book on 'The history of geophysics in Finland: 1828–1918' written by Heikki Juhani Simojoki (1906–1990) (Simojoki, 1978) covering historical account of the development of geophysics only in one particular geographical region.

After a long hiatus, the history of geophysics received general attention among the geoscientists in 2005, when the Organizing Committee of International Commission on the History of Geological Sciences (INHIGEO) held during 2–12 July 2005 at Prague, Czech Republic kept 'History of Geophysics' as the theme of the conference. Five years later, Wilfried Schröder (1941–2011), Member of the Interdivisional Commission on History of IAGA (International Association of Geomagnetism and Aeronomy), published an article titled 'History of geophysics' (Schröder, 2010), a rare yet invaluable document of its kind. Schröder (2010)

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emphasizes that unlike other disciplines in science, such as medicine, physics or astronomy, geophysics has never received any attention in discussing its historical past. The author also resonates with the perception of Schröder (2010), and holds the opinion that even the publication (Schröder, 2010) gives only a glimpse on the record of development of geophysics, which is mostly confined in the area of meteorology and geomagnetism. Interestingly, the Interdivisional Commission on History of IAGA which actually motivated Wilfried Schröder to write on history of geophysics was founded in the year 1957 on suggestion from Russian meteorologist, Nikolay Vasileyvich Pushkov (1903–1981). Note that on the historiographical point of view, Schröder's article on history of geophysics focused mainly on the activity associated with IAGA, as according to Schröder (2010) this was the major aim of the Commission.

Unlike physics and the geology, the subject geophysics is poorly perceived by many, especially those who are not trained in this subject. Often, it is believed by many including professional geoscientists that the discipline geophysics is one of the ancillary branch of geology. Similarly, it is also believed by many that the origin of geophysics dates as far back as the beginning of the seventeenth century when the solid earth was ascribed to a large magnet. Some also argue that the subject was perceived long time back by the geodesists when earth's physical surface was determined. None of those beliefs are quite right. This article is an attempt to provide historical scholarship on the origin of the discipline and its initial journey of development for hundred years since its inception.

2 Geophysics born

Julius Ferdinand Fröbel (1805–1893), German geographer, was specialised in theoretical geography which gave him a scope of looking at natural phenomena that influence nature including life in the geospace. In his textbook on theoretical geography, *Mittheilungen aus dem gebiete theoretischen erdkunde* (in German: Communications to the field of theoretical geography) Fröbel introduced the term geophysics which, as posited, would explain earth's physical conditions in the realm of experimental physics (Buntebarth, 1998; Fröbel & Heer, 1834). Some may argue that, although the specific word 'geophysics' did not arise before Julius Fröbel and Oswald Heer introduced it in their book, the concept of geophysics was, nonetheless, old. Richard Howarth argues that *La physique terrestre* (in French: Earth physics) appeared as early as 1761 in a dictionary published by French physicist, Aimé-Henri Paulian (1722–1802) (Howard, 2020). But the usage of the term 'physics of the earth' became more pronounced in German and Italian languages from the beginning of the nineteenth century (Howard, 2020). For example, Georg Friedrich Parrot (1767–1852), Baltic German physicist, published a book titled *Grundriß der physik der erde und geologie*: *zum gebrauche für akademische borlesungen* (in German: Outline of the physics of the earth and geology: for use in academic lectures) in 1815, which was the first of its kind to be precise (Parrot, 1815). The book, as the title suggests, is introductory in nature, and contains chapters on figure of the earth, gravity, earth's magnetism, atmosphere and oceans. On the other hand, the French physicist, François Arago (1786–1853) envisioned the subject as physics of the earth which he, indeed, mentioned in his book *Instructions pour la physique du globe* (in French: Instructions for the physics of the earth) published in 1835 (Lequeux, 2016). Famous British astronomer and polymath of the nineteenth century, John Herschel (1792–1871), called the subject as terrestrial physics (Herschel, 1830). Evidently, the word 'geophysics' started getting a distinct recognition, although the concept of physical description of earth's process was many centuries old.

One should bear in mind that the well-known discipline physics itself was recognised separately from the field of natural philosophy only from the middle of nineteenth century. It may be noted that the most celebrated physicist, Isaac Newton used the terminology 'natural philosophy' instead of physics in his famous book on theoretical physics *Philosophiæ Naturalis Principia Mathematica*. In fact, it was in the year 1834 when British natural philosopher and science's greatest wordsmith, William Whewell (1794–1866) coined the word 'physics' in a review article on the book of popular science titled 'On the connexion of the physical sciences' by Scottish mathematician, Mary Fairfax Somerville (1780–1872) in the journal *Quarterly Review* (Whewell, 1834). Somerville may as well be credited for the coinage of the word 'physics'. Therefore, the birth of a separate discipline as geophysics is a remarkable development in the nineteenth century.

Unfortunately, the word geophysics did not find enough usages since its coinage in the early 30s of the nineteenth century. This was possibly due to the fact that the subject belonged to a niche area of research during that period, and many were confused with the appropriateness of its nomenclature, such as whether the subject should be called geognosy (geo + gnosis) or geophysics (geo + physics). In the year 1849, German Mineralogist and Professor of Geognosy at the University of Freiberg, Carl Friedrich Neumann (1797–1873), wrote a text book on geognosy where he defined geophysics as a branch of geognosy while dealing with the earth on the whole. Note that geognosy is a branch of geology which deals with materials of the earth's structure and its exterior composition. The word 'geognosy' was coined in the late eighteenth century by German mineralogist, Abraham Gottlob Werner (1750–1817). Therefore, the word has a German background. Professor Marianne

Klemun from University of Vienna, Austria clarified about the conflicting labels 'geognosy' and 'geology'; whilst the former suggests about the study of the *origin of the earth*, the latter implies the study of the *formation of the earth* (Klemun, 2015). Such terminology was restricted only within Germany and German speaking nations. Evidently, Werner's definition of geophysics was unclear.

Nevertheless, historical records suggest that right from the inception to adolescence, the discipline geophysics was reared most effectively by the geographers rather than physicists and geologists combined. To this end, it is important to clarify the scope of geophysics in a broader sense, as question may arise in one's mind whether the physics of the ocean and atmosphere should be considered within geophysics. Truly speaking, in a broader sense those two disciplines are the wings of geophysics; however, we will restrict to the definition of geophysics related to the solid earth, as the geographers of nineteenth century did. German geographer, Ferdinand Paul Wilhelm Richthofen (1833–1905) who was famous for his work on China and especially in coining the word 'Silk Roads', mentioned about geophysics specifically in his book *Über die zentralasiatischen Seidenstrasse bis zum* 2. *Jh. N. Chr* (in German: About the Central Asian Silk Road) which was published in the year 1877. Richthofen recognised geophysics as an auxiliary science dealing especially with the solid earth while referring to scientific geography. He insisted that geographers should study geographical principle through the lens of geophysics, as the physical processes of earth's natural phenomena are intrinsically related to the geography. It may be noted that Richtofen recognised the subject geomorphology, a discipline that deals with landform, where methods of geophysics could be implemented.

2.1 Onset of geophysics in Asia

Unfortunately, it took more than three decades from Fröbel to Richtofen that the discipline geophysics got some mention. One may consider that Fröbel's mention of the term geophysics was the embryonic stage of the discipline which underwent a gestation period till the year 1877. Readers may be surprised to know that the discipline of geophysics was probably not very much alien to the Far East during the last quarter of the nineteenth century. During the rule of Meiji government in Japan there had been large scale transformation in Japanese society, which was known as Meiji restoration. John Milne (1850–1913), a young mining engineer from England working as an explorer in Newfoundland and Labrador, Canada, was hired as a Professor of Geology at the Imperial College of Engineering, Tokyo in the year 1875. Milne initiated, although rudimentary, courses on geophysics especially in the area of crystallography and seismology. In 1880 Milne developed highly sensitive horizontal pendulum based seismograph and started recording earthquakes all over Japan. With his hard work and constant cooperation from the Japanese government, he eventually established world's first seismic network in Japan. In the same year (i.e., 1880), American physicist, Thomas Corwin Mendenhall (1841–1924), who also taught at the Imperial University at Tokyo measured absolute gravity in Tokyo and also on the summit of Mount Fujiyama, Japan using Kater type seconds pendulum (Mendehall, 1881).

Interestingly, the concept of geophysics, although the word per se was never used, appeared in Indian subcontinent by the first half of nineteenth century when a geomagnetic observatory was established at Madras in the year 1822. By the year 1841, three more magnetic observatories, such as Trivandrum, Colaba and Shimala were established (Lakhina & Alex, 2007). These observatories were networked with *Magnetischer Verein* at Göttingen, established by Carl Frederik Gauss (1777–1855) in 1830. Similarly, the earliest measurement of absolute value of gravity using a compound pendulum, designed by Henry Kater (1777–1835), was made by John Goldingham (1767–1849) at Madras, India in 1821 (Goldingham, 1822). In 1862, British army engineer, Captain James Palladio Basevi (1831–1871) made pendulum based gravity survey on the eastern side of the Indian Peninsula. Captain Basevi was at that time holding the position of Superintendent, Survey of India.

Possibly influenced by the work of John Henry Pratt (1809–1871) on the effect of gravitational attraction of Himalayas on the geodetic survey near the foothills of the mountains (Pratt, 1855), Basevi planned to conduct a systematic gravity measurements from the southern most point of Indian Peninsula to up north of the Himalayas. Between 1865 and 1873, Basevi along with Captain William James Heaviside made gravity observations in 31 stations from Cape Comorin, Tamil Nadu to Ladakh, Kashmir, India using 'seconds pendulum' of Kater type on loan from the Royal Society of London (Burrard, 1905; Lenzen & Multhauf, 1965). It is also interesting to note that an early form of seismological studies were also conducted by Richard Dixon Oldham (1858–1936), Superintendent Geologist at Geological Survey of India, at the end of the nineteenth century following the Great Assam Earthquake in 1897. Oldham made three important contributions. Firstly, he identified that fault motion was associated with an earthquake. Secondly, he distinguished separate arrivals of seismic wave phases, such as P- and S-waves. Thirdly, he postulated the presence of dense core within earth. Despite, these significant works associated with geophysics, the concept of geophysics, truly speaking, was obscured. The studies were either in the gamut of natural philosophy, or at best under the category of earth sciences.

2.2 Geophysics in Europe at its early stage

Although the discipline geophysics was born in Europe by the early 30s of the nineteenth century, its growth was very slow. Interestingly, geophysical methods, such as systematic long magnetic transect measuring all three components of magnetic intensity was conducted by Karl Kreil (1798–1862), Austrian Meteorologist and Director of Prague Observatory, between 1843 and 1845 in the territory of Slovakia which was then known as Bohemia (Kreil & Fritsch, 1850). However, the first successful magnetic survey (measuring magnetic total force) with a relatively modern approach was conducted by Georg Balthazar von Neumayer (1826–1909), German Polar Explorer, in Victoria, Australia between 1858 and 1864.

During the onset of Second Industrial Revolution in the late 60s of nineteenth century, Sweden started geophysical prospecting, especially the magnetic method for prospecting iron ore deposits. The eponymous Thalén–Tiberg mechanical magnetometer invented by Tobias Robert Thalén (1827–1905) and Johan Tiberg in Sweden was used in prospecting. Interestingly, Tobias Thalén was a Professor in Physics at the University of Uppsala in Sweden and Johan Tiberg was a mining engineer. Strictly speaking, the studies on mineral prospecting in entire Europe was done under the auspices of the subject geography (Avango et al., 2018). There were well established geographical societies in Paris and Berlin as early as 1820. One such society was also established in Sweden in the year 1870.

In Soviet Russia, other than studying terrestrial magnetism, the study of earthquake seismology also started by the middle of nineteenth century. Even before the invention of appropriate seismograph, there was a serious attempt of studying earthquake seismology. However, such studies were primarily conducted by geographers and geologists. Interestingly, the Seismic Commission, a scientific body to investigate earthquake, was founded as an umbrella organisation within the Geographical Society of Russia in 1888, after a devastating earthquake at the town of Verny (now Alma-Ata at Kazakhstan). Ivan Vasiliveich Mushketov (1850–1902), Professor at the Department of Geology and Geognosy of Mining Institute of Petrograd (now known St. Petersburg Mining University) took the initiative of completing the unfinished work of seismic cataloguing by Russian geographer, A. P. Orlov, and published a comprehensive catalogue of earthquakes (with tabulated values of Rossi–Forel scale of intensity) that occurred within the Russian Empire from 1700–1888 (Mushketov & Orlov, 1893). Some, however, argue that the systematic observations of earthquake started as early as 1847 in the City of Sselenginsk, southern Siberia of Russia by a geographer, P. A. Kehlberg (Radziminovich and Shchetnikov, 2013). By the turn of twentieth century, the Seismic Commission which was an ancillary body became the Permanent Central Seismic Commission (PCSC) under the control of the Imperial Academy of Sciences. With the support from PCSC, Russian physicist, Boris Borisovich Golitsyn (1862–1916) invented in 1906, the first electromagnetic seismograph which helped to build Russia-wide seismic network (Minina, 2019). Unfortunately, the perception of separate discipline geophysics was still missing.

Geographers in Europe, in general, especially those engaged in the studies of the earth processes, soon realised the requirement of introducing a new scientific discipline geophysics, as the scope of the subject had become beyond the arena of geography or even geology. And geognosy would certainly not be the right labelling of the subject. One would naturally wonder what attributes made the discipline geophysics distinguishably different from geology. It is no wonder even someone engaged in the profession and practice of the subject remains oblivious about the difference between these two disciplines. ‘Even geophysicists were uncertain about their fields’, a statement made by Jan Kozák and David Oldroyd in their publication (2007) should not be considered as an exaggeration.

2.2.1 Definition used by Oxford English Dictionary (OED 2012)

Geology is the science which deals with the physical structure and substance of the earth while Geophysics is the physics of the earth.

2.2.2 Definition used by Encyclopedia Britannica online (EBO)

Geology is the field of study concerned with solid earth (https://www.britannica.com/science/geology) while Geophysics is a discipline that applies the principles and methods of physics to the study of the earth (https://www.britannica.com/science/geophysics).

The above definitions as per both the OED and EBO, although brief, are succinct. It is, however, interesting to note that German geographer, Siegmund Günther (1848–1923) as far back as the last quarter of the nineteenth century also held the same notion about geophysics.

2.3 Geophysics in North America

The application of geophysical methods for mineral prospecting started in U.S. as early as 1882 when American geophysicist, Carl Barus (1856–1935) used it for prospecting at Comstock Eureka Lode, Nevada (Barus, 1882). Most importantly, it was for the first time, the electrical method in geophysics was used with specific intent and objective. Truly speaking, measurement of electric potential on earth was conducted more than half a century ago when British

geologist, Robert Were Fox (1789–1877) in 1830 discovered naturally occurring electric potential which is now recognised as self-potential at the Cornwall Copper Mine in England, although Fox wrongfully claimed that as an electromagnetic potential (Fox & Gilbert, 1830). Fox predicted that measurement of electric potential could be used for prospecting ore deposits. Possibly motivated by Swedish efforts, the United States Geological Survey (USGS) in the early 90s of nineteenth century under the leadership of Henry Lloyd Smyth (1862–1944) conducted magnetic survey at Marquette District of Lake Superior iron ore deposits of the State of Michigan (van Hise & Bayley, 1895; Smyth, 1897). This was certainly one of the early attempts of conducting systematic geophysical survey in North America, although the discipline geophysics was yet to be established formally.

Soon under the leadership of American physicist, Louis Agricola Bauer (1865–1932), the discipline could lay a strong foundation in America. Louis Bauer played a crucial role, not only in promoting systematic geophysical survey, especially the magnetic survey in all the states of U.S., but also in conducting research while being a founding editor of the journal *Terrestrial Magnetism*. In the earliest volume of the journal, Bauer proudly announced that the State of Maryland in United States conducted detailed magnetic survey in the entire state. It is important to note that the Department of Terrestrial Magnetism was founded in 1904 at Washington based Carnegie Institute for Science, with the primary intent of conducting marine magnetic measurements. The institution used specially designed non-magnetic ship which operated from 1909 to 1927 until it was destroyed accidentally by fire.

Almost at the beginning of the twentieth century, geophysical methods in mineral prospecting were also inducted in Canada, although the first seismograph was stationed at Toronto, Canada in 1897. In March 1903, Canadian Mining Institute held annual meeting where the scope of using magnetometric measurements in locating magnetic ore bodies was discussed. A year later Eugene Hannel, Superintendent of Mines, Canada submitted comprehensive report where he discussed various aspects of magnetic survey including interpretation technique of measured magnetic data (Hannel, 1904). The report was so nicely presented that it should be considered as the first text book written in English on the magnetic methods of prospecting, although the discipline geophysics was yet to be formally recognised in Canada. While the application of geophysical method for ore prospecting was strongly advocated by Eugene Hannel in 1904, it took four and half decades when Canadian Society of Exploration Geophysicists was founded. Recognition of the discipline geophysics, by-and-large was slow.

But within a decade there was a tremendous turn around, especially the discovery of Turner Oil Field at Alberta in 1917. The euphoria was extreme when Reginald Fessenden (1866–1932), Canadian physicist, took a patent in 1914 to explore oil bearing strata using seismic method. Actually, Fessenden invented *sonar* (sound navigation and ranging) which could be used to determine the depth of the ocean floor. However, the first test use of seismic method was conducted not in Canada, but on 9th August 1921 in Ardmore, Oklahoma, U.S. Eight years later, in 1929, seismic survey was conducted in Turner Valley Oil Field, Alberta, Canada.

3 Early publications of books and journals

Geographers in the late nineteenth century realised that the best way to introduce the new discipline is through publication of books, research journals and introducing course curriculum at the university level. Italian astronomer and physicist, Angelo Secchi (1818–1878), published a book *Lezioni elementari fisica terrestre* (in Italian: Elementary lessons of earth physics) in 1879. The book in its first lesson introduced the figure of the earth and then continued with oceanography, volcanism, stratigraphy and palaeontology, etc. Secchi's book *Fisica terrestre* was descriptive in nature and, truly speaking, it served geology better than geophysics, as there was lack of mathematical and physical details in describing physical processes. Next bold attempt came from Siegmund Günther, who published two volumes of introductory geophysics textbook in German language. The first volume appeared in the year 1884 and the second one in the following year. The title of the book *Lehrbuch der geophysik und physikalischen geographie* bands I and II (in German: Textbook on geophysics and physical geography, volumes I and II) (Günther, 1884–1885). In the preface of the book, Günther was advocating to the would-be-reader (possibly the first year undergraduate students in the university) that why prior knowledge of mathematics and physics are essential in true understanding of geological processes. He even recommended students to read the report of German mathematician, Karl Bernhard Zöppritz (1881–1908) which was published in Wagner's journal *Geographisches Jahrbuch*. Interestingly, during late nineteenth century there was no true geophysics course offered by any European university, and as a matter of fact nowhere in the globe as well. Therefore, the textbook of Siegmund Günther was meant for graduating geographers who would get some essence of geophysics.

Next bold attempt was on bringing scientific publications with a major focus on geophysics, which would act as a precursor to forming a learned society in geophysics. The famous German geographers, Herman Hans Wagner (1840–1929) and Ernst Behn (1830–1884) were in the editorial role of the famous journal of geography in German language *Geographisches Jahrbuch* (in German: *Annals of Geography*) in 1872. Wagner had a brilliant idea. He wanted

to give an edge to his geography journal in order to increase more readership and circulation among disparate group of researchers. He convinced his fellow editor, Ernst Behn that the vision of German geographer, Paul Richthofen, could be executed by inducting some researchers in the editorial board who were primarily working on the area of physics of the earth's processes; for example, geomagnetism, earthquakes and its physical/mathematical description so on. In other words, Wagner attempted to bring notice to the readers of his journal about some scope of geophysics.

Wagner's task was simplified when German anthropologist and geophysicist, Georg Cornelius Karl Gerland (1833–1919) became one of members of the editorial board of the journal. Although the journal *Geographisches Jahrbuch* dedicated one section for publishing geophysics between 1881 and 1885 but, it was difficult to get enough articles related to geophysics. Even the concept of seismology was premature and majority of seismological works in the last quarter of the nineteenth century were merely crude observations due to lack of appropriate instrumentation. Nonetheless, the perception of mechanical properties, such as theory of elasticity of earth materials and propagating kinematic disturbances as wave had been developing within some group of physicists and applied mathematicians. In December 1887, Cornellius Gerland founded a highly prestigious journal in German language, known as *Gerlands Beiträge zur Geophysik Zeitschrift für Physikalische Erdkunde* (in German: Gerland's Contributions to the Geophysics Journal of Physical Geography). Four months later, in the April issue of the magazine *Science* a review of the world's earliest technical journal on geophysics appeared. A brief excerpt of the review by the editor of the magazine *Science* is given below.

> [... It illustrates the method of geography teaching at German universities better than any elaborate description could do. As indicated in the title it contains the results of researches of members of the geographical *Seminar*. ... In the introduction, Professor Gerland gives his views on the aim and scope of geography. ... On the other hand, he does not consider the methods of geology, so far as they are founded on palaeontology, as the proper field of geographical studies, and confines the latter to the study of the problems of geophysics: i.e., the study of the physical and chemical forces as acting upon the earth. ...] (Editor Science, 1888).

It was not quite right, as mentioned by the editor of *Science* magazine, that *Beiträge zur Geophysik* was the earliest journal in geophysics. In fact, the *Transactions of Seismological Society of Japan* should be considered as the forerunner of the geophysical journal, although it was publishing seismological observations including seismogram. The first publication of *Transactions of Seismological Society of Japan* appeared in June, 1880. Nonetheless, the journal *Gerlands Beiträge zur Geophysik* was certainly the corner stone of the development of geophysics. Unfortunately, the journal struggled severely due to the lack of articles on geophysics. Between 1888 and 1898 only three volumes of the journal were published.

However, the situation improved dramatically with the turn of the new century. In the first half of the twentieth century *Gerlands Beiträge zur Geophysik* was the leading journal on geophysics. It would be surprising to many geophysicists to know that the famous physicist, Albert Einstein (1879–1955) was a member of the editorial board of the journal during 1926–1933 (Schröder & Treder, 1997). By then the coveted journal made a time travel for almost four decades; a great feat indeed to support the discipline geophysics from its juvenile state to maturity. The journal *Beiträge zur Geophysik* continued to be published over a century, until it stopped publishing from the year 1990.

Within a decade from the day of foundation of the first journal on geophysics, the leading American geophysicist of the late nineteenth to early twentieth century, Louis Agricola Bauer (1865–1932) introduced a new journal *Terrestrial Magnetism* in the year 1896 which has been known since March 1949 as *Journal of Geophysical Research*, the flagship journal of American Geophysical Union. Agricola Bauer was the founding member of the journal till 1932. From the second decade of twentieth century, more journals on geophysics started appearing. For example, Ludger Mintrop (1880–1956), German mine surveyor and geophysicist, who developed seismic refraction method in the year 1917 established the *Zeitschrift für Geophysik* in 1924, which was rechristened in 1974 as *Journal of Geophysics*. Twelve years later, from the year 1936 the journal *Geophysics*, the flagship journal for professional geophysicists, especially focussing on publishing research works related mainly to prospecting hydrocarbon and other mineral resources started regular publications of research articles under the banner of Society of Explorations Geophysicists, Tulsa, Oklahoma.

4 Establishing learned societies

One of the oldest learned societies in geophysics, other than *Magnetischer Verein* which was founded in 1830, was the Seismological Society of Japan, which was established in 1879 with organised efforts from John Milne, James Alfred Ewing (1855–1935) and Thomas Corwin Mendenhall (1841–1924). The founding president was, however, Japanese politician, Hattori Ichizo. Truly speaking, *Magnetischer Verein* should not be counted as one of the learned societies of geophysics as the terminology geophysics was yet to appear. In fact, Milne's horizontal pendulum seismograph which was a remarkable development in 1887 was a

trend setter. Milne's seismographs were installed in several places in Japan in order to build a seismological network. James Ewing in a publication to the journal *Nature* in 1886 described how the Seismological Society of Japan carried out remarkable works on seismology including publication of *Transactions of the Seismological Society of Japan* (Ewing, 1886). Earthquake observations in Japan with the help of nation wide network of seismometers helped Japanese seismologist, Fusakichi Omori (1868–1923) to propose the eponymous law, according to which the frequency of aftershocks from an earthquake decreases with the reciprocal of time. John Milne's return to England boosted idea of coordinated seismic network installation in all five continents. By the year 1899, there were 27 coordinated seismic networks operating in all five continents except Antarctica (Herbert-Gustar & Nott, 1980) and by 1903, 13 more seismic stations were connected to the world wide seismic network (Helffrich, 2013).

An early ambitious international scientific collaboration in geosciences in general and geomagnetism in particular was initiated during the first International Polar Year (IPY) 1882–1883, which made significant influence on the development of geophysics (Baker, 1982; Taylor, 1981). This was not the first and the only effort of building international scientific collaboration in the nineteenth century. In fact, there had been at least two notable efforts of international scientific cooperation made by the first half of the nineteenth century. Those are: (i) Gauss–Weber initiation in building global collaboration in the late 1830, called *Magnetischer Verein* with the objective of studying temporal variation of geomagnetic elements (declination, inclination and intensity) globally, and (ii) the world astronomical cooperation (1849–1852) to determine solar parallax more accurately, as the reported value of the measured solar parallax 8.57116″ from the data of transit of Venus in the years 1761 and 1769 by German astronomer Johan Franz Encke (1791–1865) in 1824 cast considerable doubts among the researchers about its accuracy (Huffman, 1991). Several nations from northern and southern hemispheres participated in the program (Baker, 1982), although it has been recognised as Naval Astronomical Expedition of United States of America (Huffman, 1991).

The first IPY (1882–1883), nevertheless, carries a special significance, as it ushered not only a new frontier of collaboration on researches on geomagnetism, but also helped in forming an umbrella organisation in geophysics, the International Union of Geodesy and Geophysics (IUGG), in the year 1909. It is, however, important to note that the International Association of Geomagnetism and Aeronomy (IAGA), one of the eight sister associations of IUGG, was founded in 1873, but in those days it was known as Commission for Terrestrial Magnetism and Atmospheric Electricity (Fukushima, 1995; Mandea & Petrovský, 2019). Most importantly, the first IPY was a great scientific movement for geophysics which brought together eleven countries from Europe including Russia and also North America to form a consortium on geophysical research, especially on the studies of extra terrestrial effect on geomagnetism. The key person who conceptualised the IPY was Lieutenant Karl Weyprecht (1838–1881), Austro-Hungarian Naval Officer. But the first IPY was coordinated by Georg Balthazar von Neumayer (1826–1909), German geophysicist and Polar explorer owing to untimely demise of Karl Weyprecht. The four major scientific programs identified in the first IPY were (i) geomagnetic variations, (ii) atmospheric electricity, (iii) earth currents and (iv) meteorological parameters. Further, the measurement schedule of thirty four permanent magnetic observatories established in other parts of the world (some of which had been operating for more than four decades) was synchronized with those of newly established stations of the Arctic regions (Baker, 1982; Taylor, 1981).

The program of the first IPY actually popularised the upcoming discipline geophysics. In the year 1919, American Geophysical Union (AGU) was founded by National Research Council of America with a mission of promoting geophysical endeavours and mutual cooperation with other international organisations. But neither the IUGG, nor the AGU is older than the Seismological Society of America which was established in 1906 at Albany, California due to strong persuasion from Alexander George McAdie (1863–1943), American meteorologist, after San Francisco earthquake on 18 April 1906. The society publishes the flagship journals *Bulletin of Seismological Society of America* since 1911.

5 Geophysical applications in prospecting

Although the geophysical methods of prospecting for mineral resources were attempted in the later half of nineteenth century, especially in Europe, its potential usage with full recognition started by the start of twentieth century. This was chiefly due to enhanced demand for mineral resources. In the beginning of the twentieth century, the second Industrial Revolution attained its peak which resulted in increase in demand of mineral resources by manifold compared to that of nineteenth century. This in turn encouraged developing geophysical methods as powerful tools of exploration. But the notable development was transforming piece-meal effort to a coordinated one by establishing geophysical service company in 1926 by French entrepreneurs and researchers, Conrad (1878–1936) and his brother Marcel Schlumberger (1884–1953). The Schlumberger brothers were actually engaged in geophysical prospecting business privately for quite some times. They were operating not only in Europe, but also in North America in the early 20s of the twentieth

century. The newly established geophysical service company, headed by Schlumberger brothers, Conrad and Marcel, and their brother-in-law, Henri George Doll (1902–1991), was involved in conducting geophysical method of exploration, especially borehole logging in oil exploration.

After the First World War, in the 20s but before 30s of the twentieth century, the economic boom in U.S. resulted in increased demand for resources. The hydrocarbon industry which started in the late nineteenth century took great initiative in exploring new hydrocarbon reserves. The geophysical methods which were emerging techniques of exploration received astounding welcome. Soon, professionals engaged in geophysical methods in exploration found the need of establishing Society of Exploration of Geophysicists (SEG) in 1930. The society was financially supported by several resource based companies, especially by hydrocarbon industries. The SEG started its flagship journal *Geophysics* from 1936 which is continuing since then. Interestingly, there was huge development in Soviet Russia as well using geophysical methods for ore body prospecting. In the year 1931, the famous Kursk iron ore deposit in Russia was discovered using systematic magnetic prospecting method. Similarly, geophysical methods for prospecting were also used in Brazil. In the early 30s of the twentieth century, Mark Cyril Malamphy (1902-), American geophysicist working at Brazil conducted magnetic prospecting method for prospecting gold bearing quartzite vein in the State of Santa Catharina of Brazil (Malamphy, 1934).

6 University chair and course on geophysics

Herman Wagner's contribution in establishing geophysics to be recognised as an important scientific discipline not only in Germany, but also elsewhere in Europe as a whole was the most significant one. Wagner was highly influential among academicians and researchers in Europe. He played a key role in establishing a Chair in Geophysics at the University of Göttingen in the year 1898, where Emil Johann Wiechert (1861–1928), German physicist and geophysicist, became the first recognised Professor in Geophysics. Actually, in 1898 he joined as an Associate Professor in Geophysics and became a Full Professor in the year 1905. Emil Wiechert was actually a trained physicist. Initially he was working on electrodynamics and X-ray at the University of Königsberg, mentored by German physicist, Woldemar Voigt (1850–1919). It is believed (although some call it a grapevine) that Woldemar Voigt encouraged Emil Wiechert to leave the University of Königsberg. Wiechert had moved from the University of Königsberg to the University of Göttingen a year before he occupied the Chair of Associate Professor Geophysics at the University of Göttingen.

But within a short period of time Wiechert formed one of the famous Schools of Geophysics at the University of Göttingen, especially in the field of seismology. He made a rapid development in the field of seismology both in terms of theory and designing a sophisticated seismograph. In the year 1900, he designed highly sensitive inverted pendulum seismograph, and mentored a group of highly meritorious students, like Beno Gutenberg, Karl Bernhard Zöppritz and many more. With his colleague, Gustav Herglotz (1881–1953), a mathematician, he developed mathematical technique in 1910 to delineate layered structure within earth from seismological data (Herglotz, 1907; Wiechert, 1910). The studies of geophysics at a university level started on the back of seismology in the University of Göttingen.

Nearly two decades later after the establishment of Geophysics Department at the University of Göttingen, Germany, the Institute of Geophysics at the University of Bergen, Norway was established in 1917 with an initiative from Professor Bjørn Helland Hansen (1877–1957), who was famous for inventing Helland-Hansen electromagnetic photometer. Professor Helland Hansen was an oceanographer and the institute was involved primarily in research on meteorology and oceanography. Interestingly, except only the doctoral program neither the University of Göttingen, nor the University of Bremen started any geophysics undergraduate courses in the early twentieth century. On the other hand, in 1923 Soviet Russia established the first geophysical research institute, the Institute of Applied Geophysics at Moscow. The institute appointed Vladimir Ivanovich Bauman (1867–1923) as a Director, who specialised in geodesy and mine surveying and had been holding a Chair of Professor at the Mining Institute in Petrograd (now known as St. Petersburg Mining University). Bauman planned offering a course on magnetometry for the academic year 1923–1924, but unfortunately, it never materialised due to his untimely demise within a few months since he took the charge as director of the institute. It may be noted that while working at the Mining Institute at Petrograd, Bauman developed a novel technique of magnetic measurement for prospecting magnetic ore body. After his demise, Alexey Alekseevich Petrovsky (1873–1942) was appointed as a Director of the Institute. In the year 1930, the institute conferred degree to the first batch of students graduating in the discipline of 'Geophysical Methods of Exploration'.

In October 1926, Colorado School of Mines, Denver opened Geophysics Department with Carl August Heiland (1899–1956), German geophysicist who immigrated to America in 1925, as the Departmental Head. The university immediately engaged in offering courses on exploration geophysics. American seismologist, James B. Macelwane (1883–1956) stated "... prior to 1924, geophysical methods of prospecting was widely known in America. It was only in the late 1924 that the startling success of geophysical

prospecting in the discovery of oil bearing structures led to the foundation of geophysics in America within the university curricula ... (Macelwane, 1940)". Interestingly in 1928, the Government Geologist at the Department of Mines, New South Wales, Australia, Earnest Clayton Andrews (1870–1948) proposed opening the courses on exploration geophysics in Australian universities (Henderson, 2016).

7 Conclusions

The discipline geophysics is a relatively niche area in science. The historical background of the subject regarding its inception and progress as a complete well recognised discipline seems to provide a picture of how a new branch of science and technology emerges from initial struggles. The difference between the disciplines geology and geophysics, as described in the text gives a clear understanding not only to the budding graduates of the discipline, but also to those who are actively engaged in the geoscience profession. The records of past achievements in the path of its development would encourage young students and researchers in their endeavours as well.

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Data availability The historical evidences or data, if any present in the article, are available in the cited literature which are enlisted in the References of the article.

Declarations

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