19. THE HISTORICAL COLLECTIONS OF THE GEOPHYSICAL INSTITUTE OF THE UNIVERSITY OF COIMBRA, AND THEIR USE FOR MODERN SCIENCE

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Resumo: O Instituto Geofísico da Universidade de Coimbra (IGUC) foi fundado em 1864 como observatório meteorológico e magnético. As observações sísmicas só teriam início 43 anos mais tarde, em 1907. Actualmente, o IGUC possui uma das séries de registos magnéticos, meteorológicos e sísmicos maiores e melhor preservadas a nível mundial. Neste artigo falaremos sobre a fundação do IGUC, apresentaremos os registos e os instrumentos utilizados nas áreas do geomagnetismo e da sismologia e comentaremos o actual estado de preservação destas colecções. Terminaremos com uma breve introdução à utilização dos registos geofísicos antigos, como os que o IGUC possui, em estudos científicos modernos, como, por exemplo, na avaliação do risco sísmico.

Palavras-chave: Instituto Geofísico da Universidade de Coimbra; Geomagnetismo; Sismologia; Registos históricos; Instrumentação científica histórica.

Abstract: The Geophysical Institute of the University of Coimbra – *Instituto Geofísico da Universidade de Coimbra* (IGUC) – was founded in 1864 as a meteorological and magnetic observatory. The seismic observations started 43 years later at the beginning of 20th century, in 1907. Today IGUC is home to one of the longest and best-preserved series of meteorological, geomagnetic and seismic records worldwide. In this paper we write about the foundation of the observatory, we describe the records and instruments used in the fields of geomagnetism and seismology, and address the present state of preservation of the IGUC collection. We finish by briefly introducing the use of old geophysical records, such as the ones possessed by IGUC, in modern scientific studies.

Keywords: Geophysical Institute of the University of Coimbra; Geomagnetism; Seismology; Historical Records; Historical Scientific Instrumentation.

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INTRODUCTION

The many knowledge leaps housed within the University of Coimbra (UC) over the past seven centuries led to its scientific and cultural growth, and contributed to build its national and international reputation. The long history of the UC is reflected in its rich architectural and museological patrimony, in the unique works that fill its libraries and archives, and in the considerable academic contributes of its scholars. Throughout time the UC has accumulated a vast and priceless scientific and instrumental heritage, which is nowadays spread through the university's many faculties, institutes and museums. In this paper we will focus on the scientific heritage of the geophysical observatory of the UC. A Meteorological and Magnetic Observatory (*Observatório Meteorológico e Magnético da Universidade de Coimbra* – OMMUC) was first founded in the University of Coimbra in 1864. The observatory was renamed Geophysical Institute of the University of Coimbra (*Instituto Geofísico da Universidade de Coimbra* – IGUC) in 1925 due to the expansion of its fields of study beyond meteorology and geomagnetism. Throughout this paper we will refer indiscriminately to OMMUC and IGUC simply as IGUC, unless we specifically refer to OMMUC. IGUC pioneered the field of seismology in Portugal, and was amongst the first Portuguese institutes dedicated to research in the fields of meteorology and geomagnetism. In this paper we will present the characteristics and importance of the documental and instrumental heritage of IGUC. We start by explaining the conditions that led to the foundation of IGUC. We then proceed with a section on the earliest studies of Earth Sciences at the UC, which focused on Solar-

Terrestrial Physics. The following sections are dedicated to the development of research on geomagnetism and seismology at IGUC. Here we focus on the instruments and records collected and used throughout time at IGUC. We further give some examples of the use of old records, such as the ones preserved at IGUC, in modern scientific studies. Ongoing efforts aim at preserving IGUC's invaluable heritage, which owns not only museological interest but also a striking significance for modern science.

THE FOUNDATION OF THE GEOPHYSICAL INSTITUTE OF THE UNIVERSITY OF COIMBRA

In the University of Coimbra, as well as in many other universities throughout Europe, geophysical studies were first initiated in the Physics Cabinet. The first geophysical topic to deserve attention in the UC was meteorology. In the first half of the 19th century meteorological measurements were regularly made in the Physics Cabinet of the University of Coimbra (UC), located in the Colégio de Jesus building. José Maria de Abreu (1818-1871) (Ferreira, 1998) first started these measurements. Indeed, in 1840 the Cabinet of Experimental Physics started purchasing new meteorological instruments manufactured by reputable English and French instrument makers. Among these, we point out a portable pluviometer of Howard and a barometer of Jones. In September 1846 the Physics Cabinet acquired printed formularies for daily records. In 1855 a new set of instruments was purchased: two Fortin barometers, two new aneroid barometers, two thermometers Centigrade, two thermometers Walferdin of maximum and minimum and two of Rutherford, one Regnault hygrometer, a thermometograph, and an electric anemograph, amongst others (Gomes and Malaquias, 2004).

Academic theses were also devoted to applied meteorology and climatology. Matias de Carvalho submitted in 1855 a dissertation on the agricultural climate and its influence on vegetation (Gomes, 2006). This issue was part of the syllabus of the course of "Agriculture, Rural Economy, and Veterinary Technology". This syllabus further included the study of the weather, climatology and agricultural meteorognosy -— the science of prevision of the weather. The subject of weather would be the object of a second academic dissertation in 1892, by Bernardo Ayres (Ayres, 1892). Ayres wrote his thesis on atmospheric circulation and weather forecast. At this time (1890s) meteorology was also one of the topics covered in the syllabus of the Physics course. An article published in 1857 in the journal *O Instituto*, about the meteorological observations made at the University of Coimbra, proposed the set up of an observatory dedicated to climate. On March 1860 the UC submitted an official proposal to the government to create a magnetic and meteorological observatory. The Faculty Congregation argued that thermometric, barometric and hygrometric records, which were regularly published since 1852 in the journal *O Instituto*, could not continue to be officiously obtained in the Cabinet of Physics. The next step was the construction of new infrastructures to host the geophysical studies.

The construction of the building that would house the Meteorological and Magnetic Observatory of the University of Coimbra (OMMUC) began in 1862. The 19th century building was supposedly designed by the Royal Observatory services at Kew. Previous work has focused on the history of some architectural projects of the epoch, mainly concerning the two first astronomical observatories of the UC (Martins and Figueiredo, 2008; Ministério das Obras Públicas, 1951). However, detailed information regarding the building of the OMMUC observatory is lacking. Comparison with international counterparts in order to identify possible models for the architecture of the buildings also remains to be made. The OMMUC was inaugurated in 1864, still housed in the Colégio de Jesus building. Only two years later, in 1866, would the Observatory be installed in its own building (Ferreira, 1998) in Cumeada, away from urban noise and at a high elevation, in a location ideal to perform geophysical observations (fig. 1).

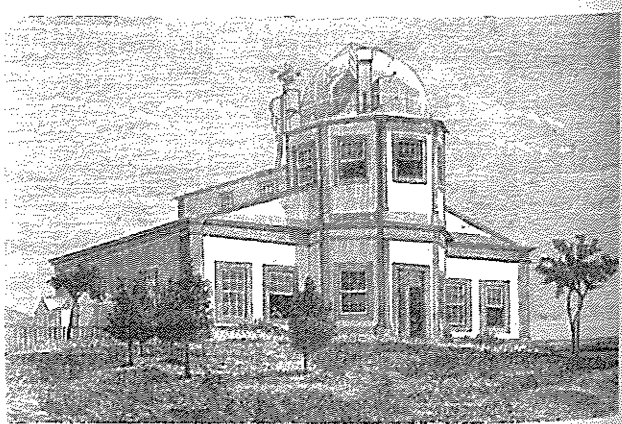

Figure 1 - Main building of OMMUC/IGUC in the year of its foundation.

Even though the OMMUC was officially founded as a meteorological and magnetic observatory, in 1864 the only observations made at the OMMUC concerned meteorology (Malaquias *et al.*, 2005; Ribeiro, 2006). The observatory was initially equipped with a barometer of Welsh with a cathetometer (which currently remains installed in its original place), a barometer of Adie calibrated by the standards of Kew and a portable barometer of Fortin, and an anemograph of Beckley. There were also a barograph and a psichrograph, both of photographic record; a psychrometer; thermometers; a udometer; an atmometer; an ozonometer; thermometers of solar radiation and the radiation to space; and thermometers for extreme temperature in the grass. Series of meteorological data are available since 1866.

In 1866 the OMMUC started recording the Earth's magnetic field. Thus, OMMUC was quickly following international advances in geophysics: Only 3 decades earlier, in 1836, had the International Magnetic Union been founded, in Göttingen, by Carl Friedrich Gauss and Wilhelm Edward Weber.

In 1891 the OMMUC acquired an Angot seismograph and initiated the study of earthquakes and seismic waves. Continuous seismic recording started in the early 1900s, along with the publication of seismic bulletins. Now also a seismic observatory, the OMMUC was renamed Geophysical Institute of the University of Coimbra (IGUC) in 1925.

THE SOLAR-TERRESTRIAL PHYSICS AND THE GEOMAGNETISM IN COIMBRA

European physicists pioneered the field of solar-terrestrial physics during the 18th and 19th centuries. Among these, the British astronomer William Herschel is distinguished as the author of early studies. The International Magnetic Union had a leading role in promoting worldwide collaborations between magnetic observatories with the goal of gaining a deeper understanding of the Earth's magnetism (Malaquias *et al.*, 2005; Cliver and Svalgaard, 2004; Kane 2005). Portugal integrated this Union in the summer of 1857 following an invitation by Johann von Lamont (from the Royal Astronomical Observatory in Munich). Adolphe Jacques Quetelet, another leader in the promotion of the international cooperation on geomagnetism, was an active collaborator in the creation of the OMMUC. In 1833 Quetelet had established, at the request of the Belgian government, an observatory in Brussels devoted to statistical, geophysical and meteorological data. The OMMUC further received extensive support from the British scientific community. The Royal Society of London (RSL) was engaged in undertaking conjoined magnetic observations in the wide basis of British Empire. Consequently, the RSL started a true Magnetic Crusade with the deployment of magnetic observation stations all over the world, from Canada to Tasmania. Edward Sabine, who was the leader of the project, persuaded the British Association for the Advancement of Science to acquire and transform the King's Observatory at Kew into the Empire's main geophysical observatory. The Observatory at Kew was intended to provide data, data standards and equipment for the network of observatories and, in fact, its guidance had worldwide impact. The Observatory of Kew was considered the main reference for the creation of the OMMUC (Bonifácio *et al.*, 2007; Malaquias *et al.*, 2005).

In the 19th century many observers studied the solar activity and kept daily logs of sunspots. One of them was the German Heinrich Schwabe (1789-1875) who, after almost 20 years of data collection, found a ten years cycle between two maxima or two minima of sunspot numbers. Nowadays, the sunspot cycle is considered to be quasi-periodic, with cycles varying from 9 to 14 years. The impact of sunspots and other solar events on the Earth generated an enlarged interest in the study of the Sun, especially due to the magnetic disturbances in the telegraphic transmissions. One of these events, the great geomagnetic storm of 1-2 September 1859, became famous both for its effects in the international telegraphic communications and for the simultaneous observations of a solar flare made by Richard Carrington (Leonardo *et al.*, 2009). Different scientists chose different approaches to investigate the Sun and its relation to geomagnetism. Astronomers focussed their research in observing the solar activity, whereas geophysicists devoted themselves to investigating geomagnetism. From the correlation between the solar observations made in astronomical observatories and the geomagnetic observations made in geophysical a new field of physics emerged: solar-terrestrial physics. (Leonardo *et al.*, 2009; Bonifácio *et al.*, 2007a,b; Cliver and Svalgaard, 2004; Kane, 2005).

Whenever a solar eclipse was predicted many scientific groups would quarrel for the best spots in the world to perform their observations. Although the determination of longitudes was an important outcome, the interest in the new solar observations was centred on the possibility of photographing the chromosphere and the solar corona, which were visible only on those rare occasions. The British astronomer and chemist Warren de la Rue (1815-89) was the one of the first to use photography in a solar eclipse at Rivabellosa, Basque Country (Spain), in 18th July 1860. Portuguese astronomers and physicists also joined international observer teams (Bonifácio *et al.*, 2006; Bonifácio *et al.*, 2007a, b; Leonardo *et al.*, 2009).

The world collaboration on solar-terrestrial physics generated an intense international activity. This can be identified as an upper level of trans-national activity, akin to any branch of the Earth Sciences where a proper spatial description of any phenomenon requires an extended network of observatories working together. The internationalisation of the scientific research on solar-terrestrial physics during the 19th century is well shown by the partaking of several geophysical and astronomical observatories, financially supported by governments in different countries. Both the Astronomical Observatory of the University of Coimbra (*Observatório Astronómico da Universidade de Coimbra* – OAUC), founded during the Pombaline Reform of the University of Coimbra in 1772, and the OMMUC were part of this international effort to study solar-terrestrial physics (Malaquias *et al.*, 2004; Bonifácio *et al.*, 2006; Bonifácio *et al.*, 2007a,b; Leonardo *et al.*, 2009). The two national observatories monitored the 1858 solar eclipse (only partial in Portugal), and the first astronomer of the OAUC and professor of Mathematics Rodrigo Ribeiro de Sousa Pinto published his measurements in *O Instituto* (*Eclipse do Sol em 15 de Março de 1858*. vol. 7, p. 22). Matias de Carvalho observed this eclipse in Brussels.

In 1860 a Portuguese expedition was organized to observe the solar eclipse at Rivabellosa, Spain. This expedition was held with the government support. The team was formed by Sousa Pinto and Jacinto António de Sousa (fig. 2), both from Coimbra, João de Brito Capello, from the Infante D. Luiz Meteorological Observatory of Lisbon, and a technician. During August and September of 1860, Jacinto de Sousa and Sousa Pinto visited the most important European scientific institutions, especially those with meteorological and magnetic observatories.

Figure 2 - Jacinto de Sousa (1818-1880), the first Director of OMMUC (between 1864-1880).

During his visit to the Observatory of Kew (August 1860), Jacinto de Sousa studied several meteorological and magnetic instruments. In particular, in his post-visit report Sousa mentions the photoheliograph used at Kew, probably the same used by De la Rue (*Relatório da visita aos estabelecimentos científicos de Madrid, Paris, Bruxellas, Londres, Greenwich e Kew por Jacinto António de Sousa*, in *O Instituto*, Secção Official, Legislação e Documentos Relativos à Instrução Pública. 1861. p. 117 - 150). Owing to the cost of the photoheliograph and admitting the possibility of further fast improvements in the field, Sousa discarded the prospect of its acquisition.

In his report Jacinto de Sousa mentions that an ordinary telescope made at the OAUC or other instruments adequate for astronomical observations were suitable for the observation of sunspots (with the goal of inferring a relation between their position, magnitude, number and some variations in the elements of the earth magnetism). The observations of the Sun would be continued in OAUC, under the direction of Sousa Pinto. In 1871 the OAUC finally bought a photoheliograph made in Germany by Repsold & Sohne and Steinheil. In 1880 the observatory purchased a new instrument to observe the Sun (ordered to A. Repsold & Sohne, from Hamburg). The new instrument, whose optical system was made by G. & S. Merz in Muenchen, allowed the observation of solar protuberances. In 1912 the research on Solar Physics at the OAUC began a period of remarkable development, which lasted throughout the 20th century. In this epoch began the execution of a plan, elaborated by Costa Lobo, to install a spectroheliograph at the OAUC. The instrument, similar to that of the Meudon Observatory, in France, was built in accordance with the specifications of the French astronomer Henri Deslandres. Due to the lack of space and conditions to place this apparatus in the OAUC building, a new location was selected, namely at Cumeada, next to the OMMUC. The section of Astrophysics of the OAUC was initially installed in the OMMUC buildings. One of the main areas of research of this sub-section of OAUC was the study of solar magnetic fields. The starting of the 1st World War forced Costa Lobo to postpone the project. In April 12th, 1925 the first spectroheliogram of the Sun was made in the UC. From that date until today the spectroheliograph has been in service (Mouradian and Garcia, 2007; Leonardo *et al.*, 2009).

GEOMAGNETISM AT THE IGUC

The Magnetic Observatory of IGUC is one of the oldest observatories in operation in the world. With a centenary tradition, the geomagnetic measurements started in 1866 in the earliest observatory located at the head office of IGUC by the hand of its first director, Jacinto de Sousa (fig. 2, table 1) (Morais, 1952).

The first geomagnetic absolute measurements of inclination (I) and horizontal intensity (H), taken in June 1866, were complemented one year later with the absolute values of declination (D) and with the continuous recordings of H, D, and Z (vertical intensity) components. The absolute measurements were carried out on a Barrow's Inclinometer (I measuring) and Gibson's Unifilar (H and D measuring), while the continuous recordings of magnetic elements (magnetograms on photosensitive paper with normal running speed of 15.2 mm/h) were obtained with a set of Adie variographs (Kew pattern) (fig. 3). After 1871, the total field (F) was directly measured using the Barrow Circle and Lloyd's method (Pais and Miranda, 1995). At the end of 1876 and beginning of 1878, two new instruments were installed – the Dover Inclinometer and the Unifilar of Elliot & Bro.s – replacing the Barrow's Inclinometer and the Gibson's Unifilar respectively (Pais and Miranda, 1995; Ribeiro, 2006). The buildings housing the geomagnetic instruments required special precautions, which were taken into account: iron was totally replaced by brass or copper and thermal insulation was so efficient that daily temperature variation was reduced to only 0.4 K.

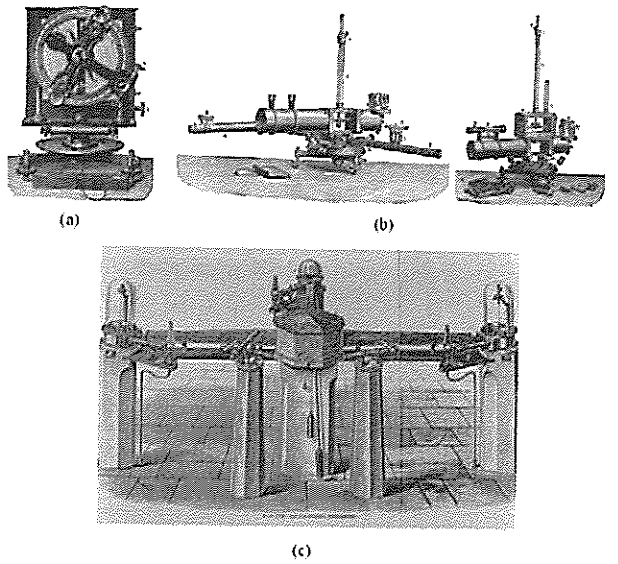

Figure 3 - The first set of magnetic instruments used at the IGUC: (a) Inclinometer of Barrow (I measuring), (b) Unifilar of Gibson (H and D measuring) and (c) Adie magnetographs (Kew Pattern) for continuous recordings of magnetic elements (magnetograms on photosensitive paper).

The installation, in 1911, of DC electric railways in Coimbra showed to be prejudicial for the operation of the magnetic observatory, and three years later the vertical magnetograph (Lloyd's balance) was discontinued due to the highly disturbed recordings (Carvalho, 1920). The installation of a new tram-line in 1929, only 50 m away from the house of the magnetographs, imposed the transference of the magnetic observatory to its present site, *Alto da Baleia*, located about 2.5 km from the city centre. The geomagnetic observations restarted in *Alto da Baleia* in 1932, but approximately during the first twenty years several logistical and operational problems affected the good functioning of the observatory. The baseline differences between the two observatory sites (*Cumeada* and *Alto da Baleia*) were not determined and the newly-acquired set of Askania magnetographs (Eschenhagen model), for the continuous recording of H, D and Z (magnetograms on photosensitive paper with normal running speed of 20 mm/h), was incorrectly installed. Additionally, the measurement techniques were oversimplified resulting in unreliable published data for that period (1932-1952) (Pais and Miranda, 1995).

It was only near the end of 1951, when a new director (Custódio de Morais) reinstalled the magnetographs and acquired new instruments for absolute measurements, that geomagnetic observations started on a regular and standard basis (Santos, 1995). This period lasted about 30 years and around 1985 the geomagnetic data began showing some non-negligible perturbations mainly related to the aging of instruments, urban magnetic noise and unreliable measurement procedures (Pais and Miranda, 1995; Ribeiro 2006). Finally, in 2007 the IGUC was able to substitute completely the old set of instruments (classic photographic recording magnetographs, Askania declinometer, QHM and BMZ) with modern ones (FGE variometers, DIM and GSM90F).

It has been recognised (Pais and Miranda, 1995; Ribeiro and Pais, 2004) that the existing long geomagnetic time series, which have been partly published since the foundation of the IGUC, show some breaks and discontinuities due to changes in the location of the observatory, equipments and observatory practices. This has led to the exclusion of Coimbra's data in some global analysis of the secular variation of the main geomagnetic field. Therefore, the complete identification and characterization of those periods of different operating conditions will aid in obtaining an improved and more complete time series, which is an essential requisite for studies of the geomagnetic secular variation.

SEISMOLOGY AT IGUC

The University of Coimbra pioneered the field of seismology in Portugal. The IGUC acquired its first seismograph in 1891, and started to continuously record the ground motion in 1904. Until today the seismic observations have continued with only a few interruptions. The seismic data recorded at IGUC constitutes the best seismic series in Portugal, both for its length and completeness.

Modern scientific investigations of earthquakes began in the 1880s and the *First International Seismological Conference* was held in Strasbourg in April 1901. Portugal was represented in the *Second International Conference on Seismology* in Strasbourg in 1903. The International Seismological Association (ISA) was founded in April 1904 and Portugal, through the UC, was among the 18 signatory states (Schweitzer, 2003).

A few professors of Physics of the Faculty of Philosophy of the UC propelled the foundation of IGUC. During more than 50 years, Physics professors occupied the director chair of IGUC. António dos Santos Viegas (1837–1914), who played a relevant role in the development of the Experimental Physics Cabinet, was also Director of the IGUC and Rector of the University for three mandates. Throughout the last years of his life Viegas was committed to developing seismology at the IGUC. In fact, Viegas' interest for seismology was officialised with his membership in the Società Sismologica Italiana.

During 1891 Santos Viegas installed an Angot B Nº 5388 seismograph, made in Paris in the Breguet workshop, at the IGUC. This instrument was purchased in June 1891 and remained in operation until 1914/15. This was the first seismograph operating in Portugal. In April 1903 Viegas installed a new seismic instrument – a horizontal pendulum of Milne (fig. 4). His last unfinished scientific project was the installation of a modern Wiechert seismograph. Viegas deceased in 1914 leaving behind him the foundations of seismology in Portugal.

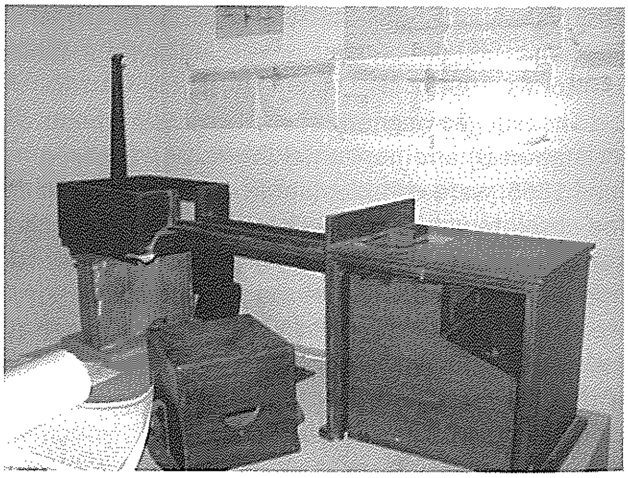

Figure 4 - Milne seismograph photographed in 2009.

The Milne seismograph recorded ground motion along only one horizontal component of motion (EW) and amplified ground-motion by a factor of ten at a velocity of 1 mm/min. This was the only seismograph operating in Portugal at the time of the devastating earthquake of 1909, which occurred near the village of Benavente (magnitude 6) (Dineva *et al.*, 2002; Stich *et al.*, 2005). Thus, the only seismogram recorded in Portugal of the Benavente earthquake was obtained at the UC.

Seismology became a hot topic in Portugal after the Benavente earthquake. A new seismic network was deployed following this destructive event, with stations located in Lisbon, Coimbra and Porto. Within the scope of the renovation of the Portuguese seismic network, IGUC acquired two long-period Wiechert seismographs. One of the instruments was installed in the last trimester of 1914 and recorded the complete horizontal ground motion (EW and NS) (fig. 5A); the second was installed in 1926 and recorded vertical ground-motion (fig. 5B). These two seismographs recorded the ground-motion amplified by factors of 200 and 80, respectively.

A B

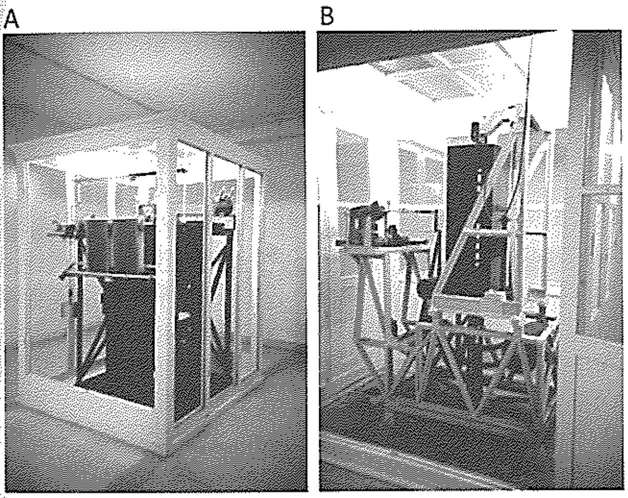

*Figure 5 - Wiechert seismographs photographed in 2009. **A** - Horizontal astatic seismograph. **B** - Vertical seismograph.*

The Wiechert seismographs were sensitive enough to allow for a decent seismic analysis of the recorded waves. Consequently, staff at OGUC started producing seismic bulletins. The publication of monthly bulletins first started in January 1915. The seismic bulletins produced at IGUC were exchanged within a large network of institutions, according to the norms of the Seismological International Association (Carvalho, 1946).

During the decade of 1950 the observatory added to its instrumentation a vertical short-period Grenet seismometer (fig. 6). The vertical Wiechert and Grenet seismographs remained in use until the end

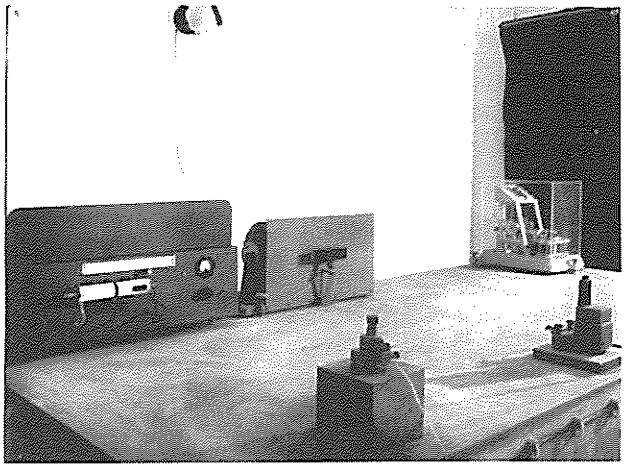

Figure 6 - Grenet seismograph.

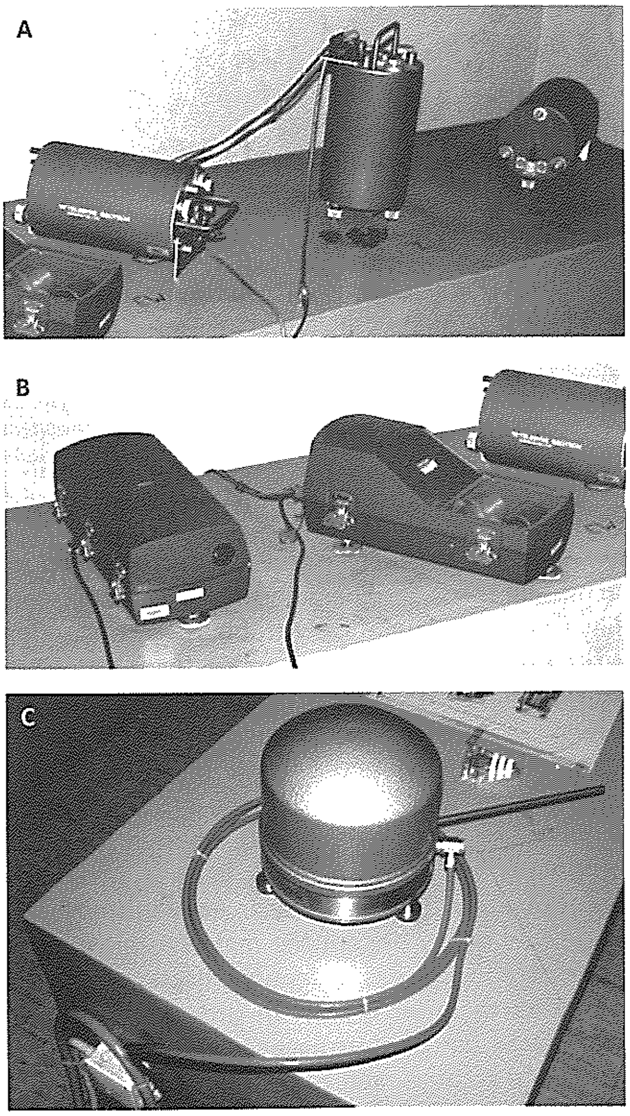

*Figure 7 - Modern seismographs photographed in 2009: **A** - Geotech S13 short period; **B** - Geotech SL210 long period; **C** - STS-2 broadband.*

of the 20th century. In 1972 IGUC acquired six modern seismometers: three to record short periods (fig. 7A) and another three to record long periods (fig. 7B), all of them based on electro-magnetic induction. The most modern seismometer at IGUC is a state-of-the-art STS-2 broadband instrument (fig. 7C). Different shelters were built throughout time for the installation of the different seismometers (fig. 8).

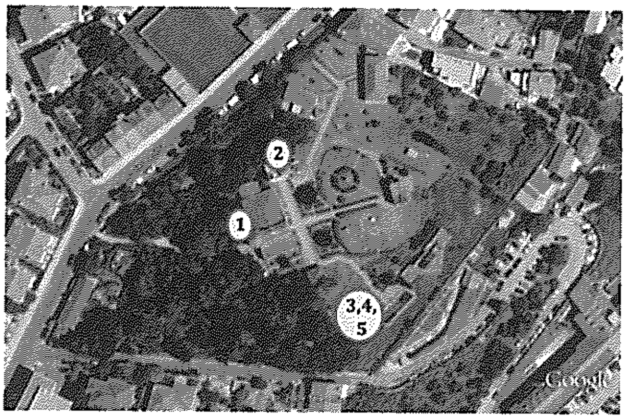

Figure 8 - Map of IGUC with locations of the several seismometers. See corresponding location annotations in Table 2. Satellite image from Google Maps. The Angot seismograph was installed in the main building of IGUC (1). The Milne seismograph was installed in an octagonal pavilion built specifically for the purpose (2). The Wiechert seismographs were installed in a basement, again specifically built as a shelter for these instruments (3). The shelter was amplified in order to receive the Angot seismograph (4). Finally, the seismo-basement was completely rebuilt in the 1970s in order to accommodate the modern Geotech seismometers (5).

Since the beginning of seismic instrumentation, in the late 1800s, the characteristics of seismometers have evolved dramatically (table 2). The working principle of seismometers advanced from rudimentary pendular mechanisms to complex electromagnetic mechanisms. The Angot seismometer, the first seismic instrument that operated at IGUC, recorded the ground-motion amplified by a factor of only 10, whereas the STS-2 amplifies the ground motion by a factor of approximately 1000. Whereas in early seismograms one could barely discern the main seismic phases, nowadays one can easily identify reflections from the many Earth inner layers. In order to study an earthquake, one needs to have seismograms recorded at several stations, and the different stations must be precisely synchronized. Therefore, clocks have always been a delicate issue in seismology. Early instruments had precise clocks attached (often pendulum clocks), which were set right every night by astronomic observations. Current seismometers receive the time signal from GPS receivers. The recording media used by the seismometers has also changed. At IGUC the media used includes photographic paper, smoked paper, chemical paper and normal white paper. At present all seismic records obtained at IGUC are digital. The technicians at IGUC regularly analyzed the seismic data and, after exchanging data with other observatories, produced monthly and yearly seismic bulletins. Printed bulletins exist only for a few periods of time (Table 3).

Today IGUC owes in its collection the following seismographs: a Milne (in use between 1903 and 1941), a horizontal Wiechert (1914–1969), a vertical Wiechert (1926–1997), a vertical Grenet (1961–1997), three short-period Geotechs (1972–present), three long-period Geotechs (1972–present), and a broadband STS-2 (2007–present) (Table 4). The Geotech and STS-2 seismometers still remain in operation. The other instruments have become obsolete for modern observations, but remain of top importance for studies of historical seismicity. Ongoing efforts at IGUC aim the restoration of the Milne, Wiechert and Grenet seismographs. All these instruments are fairly well preserved and their restoration appears feasible. Restoring these old seismographs back to operation will allow a complete study of their working characteristics, which in turn will allow for a better study of the old seismograms. Re-visiting old seismograms with modern techniques is a current practice that provides a valuable help in assessing earthquake hazard.

The IGUC records of the most important European historical earthquakes have recently been digitized within the scope of the European project SISMOS. All the digitized seismograms are freely available on-line at http://sismos.rm.ingv.it/ and http://storing.ingv.it/es_web/. Modern seismic analysis techniques have already been applied with success to Coimbra's old seismograms, enabling the extraction of new scientific information (Samardjieva *et al.*, 1998; Dineva *et al.*, 2002; Battló *et al.*, 2008). From the re-examination of old seismic records it is now possible to obtain more accurate hypocenter locations, better magnitude estimates, and new focal mechanisms for earthquake sources. This information is invaluable in a country like Portugal, located in a tectonic setting characterized by low convergence rates, which result in long recurrence rates between seismic events. In other words, the time interval between large earthquakes is long. Nevertheless, when earthquakes do happen, they have the potential to be devastating, which has happened historically (e.g., January 26, 1531; December 27, 1722; November 1, 1755; or even February 28, 1969) (Baptista *et al.*, 1998a,b; Baptista *et al.*, 2007). In order to study the seismicity in a setting of low tectonic rates one must use a seismic record that goes as further back in time as possible. In the case of Portugal, the study of old seismograms is a powerful tool to improve the quality of seismic hazard assessment, and consequent earthquake risk mitigation.

CONCLUSIONS

The Coimbra magnetic observatory has a secular tradition in monitoring the geomagnetic field and its long-time recordings represent an invaluable scientific data set for geomagnetic studies despite the relatively important perturbations that corrupt some periods of data. Thus, it is essential to proceed with a critical evaluation of all geomagnetic records in order to get a better quality of data series. On the other hand, the precious archive of historical magnetograms and hourly mean tables should be inventoried and digitised. Such database would allow for the preservation of old analogue geomagnetic data from their irreversible loss, and for dissemination through digital libraries and archives. The old analogue magnetograms can nowadays be used in the determination of geomagnetic activity indices and in the study of great historical geomagnetic storms and associated auroras (space weather studies) (Vaquero *et al.*, 2008). Additionally, these historical records can also be used in the calculation of the magnitudes of past earthquakes, helping to complete the seismic catalogues in the second half of 19th century (Batlló *et al.*, 2005).

The IGUC led early seismology in Portugal. Today IGUC is home to the longest series of seismic records in Portugal, and to a wonderful collection of fairly well-preserved seismographs. Ongoing efforts aim the restoration of the older seismographs for further studies of historical seismicity. The most important historical seismograms of IGUC have already been digitized (within the scope of the European project SISMOS) and are freely available on-line. Some of these seismograms have already been successfully used in modern seismic studies. Such studies are key to improve the quality of seismic hazard assessment, and consequent earthquake risk mitigation.

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Table 1 - List of directors of IGUC since its foundation in 1866 until 1974.

Time Period	Director of OMMUC/IGUC	Academic Position
1864 – 1880	Jacinto António de Sousa	Professor of Physics
1880 – 1890	António dos Santos Viegas	Professor of Physics
1890 – 1892	António de Meireles Guedes Pereira Coutinho Garrido	Professor of Physics
1892 – 1906	António dos Santos Viegas	Professor of Physics
1906 – 1907	Henrique Teixeira Bastos	Professor of Physics
1907 – 1914	António dos Santos Viegas	Professor of Physics
1914 – 1948	Anselmo Ferraz de Carvalho	Professor of Physics, Geology and Mineralogy
1949 – 1950	João Rodrigues de Almeida Santos	Professor of Physics
1950 – 1960	José Custódio de Morais	Professor of Geology
1960 – 1961	Manuel Neto Murta	Professor of Mathematics
1961 – 1963	José Veiga Simão	Professor of Physics
1963 – 1974	Fernando Pinto Coelho	Professor of Chemistry

Table 2 - Characteristics of the several seismometers operated by IGUC.
Question marks indicate fields that need to be confirmed.

	Angot EW, NS, Z (?)	Milne EW	Wiechert EW, NS	Wiechert Z
First ordered	1891	1900	1910	1926
Time of operation	1891 – 1899+	1903 – 1941 (?)	1914 – 1969	1926 – 1997
Existing records	None	1904 – ?	Nearly complete collection.	Nearly complete collection.
Location	Inside the main building (1)	Octogonal pavilion (2)	Seismic pavilion (3)	Seismic pavilion (3)
Working principle	Vertical Pendulum	Horizontal pendulum	Inverted pendulum	Vertical pendulum
Record	Ground displacement	Ground displacement	Ground displacement	Ground displacement
Rotation velocity	Low	1 mm/min	15 mm/min	15 mm/min
Amplification	?	x10	x 200	x80, originally. In 1953/54 was adapted to x1500.
Recording Media	Paper	Photographic paper	Smoked paper	Smoked paper, originally. Adapted to photomagnetic in 1953/54.
Damping	?	None.	Air	Air
Associated clock	Inbuilt.	Pendulum clock with electrical transmission	Pendulum clock with electrical transmission	Pendulum clock with electrical transmission
Free Period	?	15-22 s	8-12 s	4-6 s
Mass	?	0.5 kg	1000 kg	86 Kg
	Grenet Z	Geotech S13 EW, NS, Z	Geotech SL210 EW, NS, Z	STS-2 BB EW, NS, Z
First ordered	1959 ?	1970 ?	1970 ?	2007 ?
Time of operation	1961 – 1997	1972 – present	1972+ – present	2007 – present
Existing records	Nearly complete collection.	Nearly complete collection.	Nearly complete collection.	Nearly complete collection.
Location	Annex to the seismic pavilion (4)	Seismology basement (5)	Seismology basement (5)	Seismology basement (5)
Working principle	Electro-magnetic (EM)	Electro-magnetic (EM)	Electro-magnetic (EM)	Vertical pendulum
Record	Ground displacement	Ground velocity	Ground velocity	Ground velocity
Rotation velocity	23 mm/min			–
Amplification	x 10^3–10^4			
Recording Media	Photographic	Originally: hot stylus over chemical paper. After 1983: ink on paper. After 2007: digital (CMG DM24)	Originally: hot stylus over chemical paper (3 components of ground motion recorded in the same page). After 1983: ink on paper (records of the Z component only). After 2007: digital (CMG DM24)	Digital (Q330)
Damping	EM	EM	EM	EM
Associated clock	Pendulum clock with electrical transmission (?)	Originally: Quartz clock with radio transmission for daily hour signals. After 2007: GPS.	Originally: Quartz clock with radio transmission for daily hour signals. After 2007: GPS.	GPS
Period	1 sec	0.91 – 1.33 sec	10 – 30 sec	0.02 – 120 sec

Table 3 - Seismic bulletins produced at IGUC.

	Preliminary	Provisory	Final	Printed
1909 – 1923	X	X	X	X
1924 – 1940				
1941	X	X	X	X
1942 – 1944				
1945 – 1945	X	X		X
1946 – 1950				
1951 – 1959	X	X		X
1960				
1961 – 1963	X	X		X
1964 – 1969	X			
1970 – 1972	X			X
1973 – 1980	X	X	X	X
1981	X	X		
1982	X		X	
1983 – 1984	X	X		
1985 – 1986	X	X	X	
1987 – 1996	X			

Table 4 - Complete list of seismometers used at IGUC.
Each column indicates a decade; each row indicates an instrument.
Question marks indicate time periods when the operation
of the instruments is uncertain (more research is needed).

	1890s	1900s	1910s	1920s	1930s	1940s	1950s	1960s	1970s	1980s	1990s	2000s
Angot EW, NS, Z(?)	X	?										
Milne EW		X	X	X	X	X						
Wiechert EW-NS			X	X	X	X	X	X				
Wiechert Z				X	X	X	X	X	X	X	X	
Grenet Z								X	X	X	X	?
Geotech CP EW, NS, Z									X	X	X	X
Geotech LP EW, NS, Z									X	X	X	X
STS-2 EW, NS, Z												X