Pergamon

Stud. Hist. Phil. Mod. Phys., Vol. 31, No. 3, pp. 371–404, 2000

Printed in Great Britain
1355-2198/00 $ - see front matter

Crossing the Olentangy River: The Figure of the Earth and the Military-Industrial-Academic-Complex, 1947–1972

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This paper explores the history of a unique assemblage of researchers in the geodetic and allied sciences organised at Ohio State University (OSU) in 1947 at the beginning of the Cold War. From about 1950 to 1970, the OSU geodetic sciences group was the most significant group of geodetic researchers in the world. Funded almost entirely by military and intelligence agencies, they pioneered the technologies, organised the research initiatives, ordered the data sets, and trained the generation of geodesists who eventually created the Cold War Figure of the Earth to both prosecute and prevent global nuclear war. They devised elaborate mechanisms to pursue in secrecy and isolation research that had hitherto been performed collaboratively and globally. They invented methods to maintain professional associations and protocols, both to distribute—and disguise—the fruits of their geodetic research. In accomplishing this, their work also undermined the basic hypothesis of isostasy that had been foundational to geodesy for the previous century.

Fundamental progress in the geosciences and military and intelligence directives were inextricably linked during the Cold War, although the extent of their convergence has been masked by the security protocols organised to disguise it. With the declassification of key programmes underway, it is now both possible and necessary to substantially revise the history of Cold War-era geosciences and their associated technologies.

Keywords: Geodesy; Geodetic Sciences; Cold War; Ohio State University; CORONA; World Geodetic Science

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PII: S1355-2198(00)00017-4

1. Introduction

Significant research on Cold War science and technology has centred on the great labs created to wage the Second World War through basic and applied physics, such as the MIT Radiation Laboratory and the Applied Physics Laboratory of Johns Hopkins University. Research has centred also on the labs' postwar evolution, and the complex relationships between civilian scientists and universities and military and intelligence institutions that lie behind the stream of complex technologies—nuclear weapons, radars, computers, ICBMs—that have issued from the labs.

The Cold War was a struggle both to prosecute and prevent nuclear war. Such a war would be waged by bombers, submarines and missiles deployed at point *A* and targeted toward point *B*. There has been considerable historical work on the applications of physics to weapon systems, and the ways in which institutions of physics were reordered by such efforts, and the parallel reordering of military and intelligence institutions.[1]

There has been relatively little attention paid to the essential role played by fundamental progress in the knowledge of the distance, direction and gravity field between any given points *A* and *B*. This is perhaps most clearly seen in Donald MacKenzie's celebrated (1990) book *Inventing Accuracy: A Historical Sociology of Nuclear Missile Guidance*. His meticulous analysis of the development of the inertial guidance systems at the MIT Draper Lab concentrates almost entirely on the story revolving about the instrumentation for accurate guidance of a device to a designated target, and the institutional histories behind the instruments. The other half of the story, left unexamined, concerns the accuracy of knowledge of the spatial relationship between the points. Simply put, the efficacy of a weapon system delivered with 'perfect' accuracy to a specific point will fail if the intended target does not actually lie at that point.

The history of the geodetic sciences at Ohio State University is a primary chapter of this other half of this story. Geodesy is the science of the shape and size of the earth, the 'Figure of the Earth', and the precise location of specific points on or near the earth's surface. Geodesy by its nature is global in scope and execution. From the establishment of Gauss's Magnetic Union in the early nineteenth century to the present International Union of Geodesy and Geophysics, geodesy as a fundamental earth science worked collectively, and geodesists fostered and organised international assemblages and scientific unions. The products of geodetic advance, such as measuring instruments, mapping systems, and descriptions of reference ellipsoids, have been presented

[1] Seminal contributions to the subject of the reordering of physics institutions include: Foreman (1987), Galison (1988), Keyles (1990) and Schweber (1991). For analysis of the historiography of this subject, see especially Foreman (1997), Doel (1997a) and Doel (1997b). Analyses of reordering of military and intelligence organisations by interactions with academic institutions include Doel and Needell (1997) and Richelson (1997).

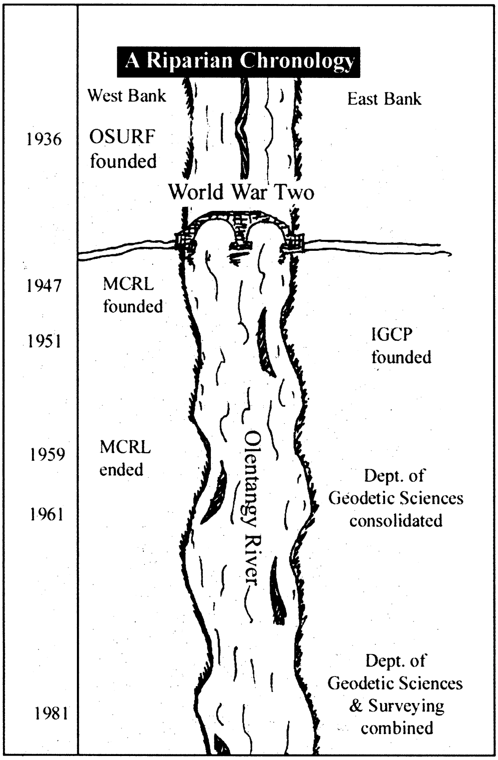

Fig. 1. *A chronology of the Geodetic Sciences at Ohio State University.*

and adopted by international legal conventions. Historically geodesy advanced cooperatively or not at all.

Geodetic progress constitutes the referencing foundation for maps and charts, which have been obviously relevant to military affairs since antiquity. Geodesy is, therefore, central to military science, but is not itself a militarised science. Geodetic progress addressed to geo-referencing even a single continent, let alone the world, has always required data and analysis from many nations. This multi-national constraint moderated the impact of military and political conflict on geodesy; before the Cold War every nation certainly gained more than it lost by sharing data.

This geodetic history at Ohio State University begins with the new era, when the trade-offs became much more ambiguous and the stakes much higher. In 1947, a unique research focus in the geodetic sciences, photogrammetry, and cartography were established in Columbus, Ohio through the Ohio State University Research Foundation. The work of scientists in Columbus became a centre and fulcrum of geodetic research and education on the planet, and remained so for about two decades (1950–1970) (see Fig. 1). It was almost entirely funded throughout by the Department of Defense (DOD) and the

Intelligence Community. Today, the products of their research extend from every public American map to the deepest and most closely held intelligence secrets of the US government.

This paper describes the history of the set of organisations created for research, instruction, and application of the geodetic and allied sciences at Ohio State University, beginning before the Second World War. The geodetic sciences continue to the present, but my analysis ends in the middle 1970s, culminating with the completion of two major classified programmes, the CORONA reconnaissance satellite programme (1958–1972) and the World Geodetic System of 1972 (WGS 72).

Ohio State University straddles the Olentangy River asymmetrically. On the eastern bank lies the university as it is traditionally known—the crowded campus, the libraries, and the enormous football stadium. It is the curricular side of the river. Across the river to the west is the extra-curricular university possessed by every campus: the dining hall warehouses, the dairy herds and experimental orchards, the campus airport, the research archives, the motor pool. The western side of the river was, traditionally, the site for externally-funded, extra-curricular research and development. The geodetic sciences were established on the western bank of the Olentangy River, and over a period of decades they crossed the river to the eastern shore. Behind that shift in position lies a sea change in the geodetic sciences and the great transformation of Cold War American science and technology.

2. The Geodetic Sciences Before and During World War II

The earth sciences were represented at OSU from its opening in 1873 in the School of Natural History. By the end of the nineteenth century, departments of Geology and Geography were established, along with a programme in surveying in the department of Civil Engineering. A programme in geometric geodesy[2] expanded out of surveying, still situated in Civil Engineering.[3]

In November, 1936, the Ohio State University Research Foundation was established on the western side of the Olentangy River to direct and administer outside-contracted research by individuals and organisations of the university. Within a year, Professors Edwin Coddington, Oscar Marshall, and George Harding, all from Civil Engineering, proposed that the university establish 'an International Institute for the Sciences of Earth Measurement and Representa-

[2] Geometric geodesy addresses positioning relative to a reference ellipsoid, a theoretical geometric figure. Physical geodesy addresses positioning relative to the geoid, which is a equipotential gravitational surface—classically, approximated by the mean level of the sea.

[3] Major historical sources for OSU departments include the many chapters of the OSU Centennial Histories, written to celebrate the 100th anniversary of the charter of the university in 1869, although the university as such opened in 1873. Principal sources for the earth sciences include Merchant (1969), Smith and Taaffe (1969) and Speiker (1969).

tion, Geodesy, Cartography, Photogrammetry and Electronic Mensuration'. Although well-established training centres for these subjects existed at universities in Holland, Sweden, Switzerland, Great Britain, Germany, Italy, and the Soviet Union, there was no comparable programme in the western hemisphere.[4] The university failed to adopt the proposal. It required global war to change their mind.

The original research contracts of the OSU Research Foundation (OSURF) were made with local and regional industries and corporations. (OSURF contract No. 1 was with Proctor & Gamble, for research on emulsifying agents). Around 1940, organisations of the Federal government began to contract with the OSURF, and by the time of official American entry into the war, contracts with civilian and military agencies outnumbered corporate research contracts. A major portion of the latter contracts as well were war-related and ultimately government funded. By 1943, the OSURF contract with the Manhattan Project, for example, was assigned OSURF No.155. The work was framed as a standard contract, although the purpose of the research was noted as: 'Not stated—Secret'.[5]

The campus on the eastern shore mobilised for the war as well. Guy-Harold Smith, the chair of the OSU Geography Department, helped organise the Army Specialized Training Program on campus. He also produced classified physiographic maps of Japan for use in the Pacific Theatre. Cartographer Arthur H. Robinson left the department for Washington DC, and by the end of the war he was chief of the Map Division of the Office of Strategic Services, the predecessor of the CIA (Moellering, 1991).

Professors Coddington and Marshall remained in the country during the war, although their research and teaching shifted to support of war-time training in Columbus, and to accelerated land surveying for the Tennessee Valley Authority, in the area of a small town named Oak Ridge, Tennessee. Professor George Harding spent the war in strategic reconnaissance and cartography. During 1940–1942, he was Chief of the Foreign Map Section of the Office of the Chief of Engineers of the Army. From 1942–1944, he was Chief of the Survey Liaison Office, General Headquarters of the Middle East, then attached as Map Officer to the 1st Army for the invasion of Normandy. He returned to Columbus with impeccable military and intelligence connections, in a radically different world.[6]

By the time Harding returned to Ohio the Cold War had already begun. Its first major skirmish was the systematic expropriation of German science and

[4] OSU Archives, Office of the President: Howard L. Bevis, RG# 3/h, Box 21: 'Institute of Geodesy, Photogrammetry, and Cartography: 1950–1955'.

[5] Ohio State University Archives Record Group (hereafter RG) 38/0/8, No 7. OSURF No.155, contract with the War Department, Manhattan District.

[6] All information derived from the OSU Archives 'Faculty Reports', all of which were written by participating faculty members and occasionally updated, and occasionally supplemented by other materials by university archives staff.

technology by Allied intelligence on one side, and Soviet and related intelligence on the other. The major project of the Allies was organised as Project Overcast, later renamed Project Paperclip.[7]

Great archives of geographic, photogrammetric, and geodetic materials were recovered from German archives and hiding places by forces on both sides. The major American effort was headed by Major Floyd Hough, then assigned to the Office of the Chief of Engineers of the Army. In November 1944, Hough and a team of several dozen men and women were dispatched to the European theatre. Their objectives were to recover Axis maps covering the Pacific theatre, in anticipation of the focus of the war shifting there after Germany's surrender, and also German and related optical and photogrammetric equipment, widely known to be superior to Allied equipment.[8]

The Hough Team recovered truckloads of their targeted materials, much of which was systematically evaluated and publicly demonstrated for American industry in the early post-war years (Gimbel, 1990, p. 102). The Hough Team also discovered a treasure trove of geodetic materials, including vast archives of German and Russian geodetic surveys made on the eastern front. The data included German and Russian geodetic surveys across Eurasia for planning the route of the Trans-Siberian Railroad. The significance of the materials was immediately apparent. As Major Hough wrote to headquarters: 'There have been found some dozen or more truck loads of documents, much of it irreplaceable, of extreme value to the War Department'.[9] The Hough materials were successfully recovered and shipped to Washington. There the horde was catalogued, analysed, and distributed to relevant cartographic and geodetic institutions, including the new Mapping and Charting Research Laboratory at Ohio State University.

The Hough materials were 'irreplaceable' for essentially the same reasons that the new OSU geodetic enterprise was critical to the progress of the Cold War. To realise why requires understanding some fundamentals of geodesy.

3. Geodesy and Geopolitics

Historically, horizontal positioning of a point on the earth's surface (such as latitude and longitude) evolved from calculations based on celestial

[7] See Lasby (1971). John Gimbel pioneered re-visiting these issues, particularly in Gimbel (1990). See also Matthias and Ciesla (1996).

[8] Interview with Dr Frederick J. Doyle, 27 October 1998 (McLean, Virginia).

[9] Quoted from the original document, in the Hough Team files, deposited in the National Archives at College Park (NARA II). The Hough Team collection is located at RG 77.11, Records of the Office of the Chief of Engineers, in the Cartographic and Architectural Records Division, NARA II. One of the only published references to the Hough Team is an article by Dille (1958) about Hough and the global geodetic surveys of the Army Map Service. Much more additional material on the Hough Team and their treasures will be presented in my forthcoming dissertation.

observations from that location. Distinct points—or stations—could be linked by measured networks, forming the geodetic basis for mapping systems. Mapping systems in the western tradition were terrestrially based, and were referenced to specific models of the shape and size of the earth, called reference ellipsoids. These systems were generally called 'datums' (from the singular of 'data') in reference to the single specific point where the mapping systems was 'tied to the ground'—i.e. linked to the reference ellipsoid.

For most of the twentieth century, for example, the geodetic foundation for the mapping systems of the US, Canada and Mexico, the North American Datum of 1923, projected from a single point at Meade's Ranch, Kansas. The Second World War was fought using national datums generated for specific national territories, but which did not correlate with other national datums. As the ranges of weapons systems grew during the war and after it, actual and anticipated conflicts became global. It became clear to the US government that national datums on continents would have to be tied to each other across ocean basins. That is, the true distances between the continents must be determined. With the development of rocketry and missile systems, the need became imperative. Only with that information could one aim Intercontinental Ballistic Missiles (ICBMs).[10] American strategic defence converged with geodetic progress, and the organisations responsible for waging or preventing nuclear war encountered the institutions and traditions of international geodesy, themselves at the leading edge of the fundamental research frontiers of the earth sciences in the twentieth century.

Determining a vertical position was and is substantially harder than finding a horizontal position. This is because vertical positions, usually height above sea-level, are expressed relative to an equipotential gravitational surface. This can be imagined by mentally extending the plane of the ocean's surface at the seashore inland running underneath mountains at a height corresponding to the gravitational level of the sea surface. This hypothetical sea level is called the geoid. However, the earth's mass is distributed unevenly, and oceanic crust is denser than continental crust. The result is that the real geoid undulates in comparison to the smooth and symmetrical figure of the imaginary reference ellipsoid (see Fig. 2).

This relationship between the geoid and the ellipsoid is expressed whenever one holds a plumb bob over a spot. If the geoidal surface and the reference ellipsoid surface are parallel, then the plumb bob points to the centre of the earth and the line of the plumb bob is truly vertical. If the geoid and ellipsoid do not coincide, which is more usually the case, then the plumb bob is perpendicular to the local surface of the geoid, and does not point to the centre of the earth. The angle between the direction the plumb bob points to and the true direction to

[10] Achieving accurate measurements of inter-continental distances would prove critical as well to determining whether or not the continents moved relative to each other, and if they did, then how and why.

GEOID-ELLIPSOID RELATIONSHIPS

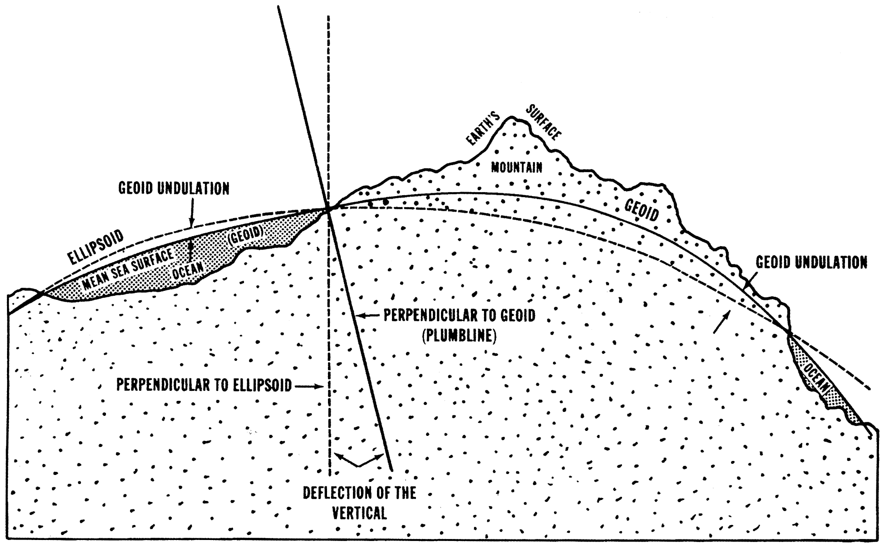

Fig. 2. *The relationship between the geoid and the reference ellipsoid, and the deflection of the vertical. (From: Geodesy for the Layman (see footnote 47).)*

the centre of the earth is called 'the deflection of the vertical'. Determining the deflection of the vertical at a spot can be critical to the earth sciences, in that it is the key to determining the true directions of 'up' and 'down' at a given point. It is also absolutely indispensable to aiming ICBMs.

An approximation of the geoidal undulation, relative to the reference ellipsoid, can be made by calculating the deflection of the vertical at a sufficient number of specific points and interpolating between the points. However, specific points generally mean places on the land surface. By 1849, the British mathematician Sir George Gabriel Stokes (1819–1903) had devised a formula to calculate the geoidal undulation of any specific point, but to solve the function one needed gravity data for many points distributed over the entire globe. Reliable measurements of gravity at sea, however, were completely impossible at the time. In the 1920s the Dutch geodesist F. A. Vening Meinesz invented a multiple pendulum apparatus that could be used in submarines (Oreskes, 1994). This made it possible to collect gravity measurements over the major part of the earth's surface—at least by those organisations that could afford or had access to submarines. In sum, there had been much progress in theoretical geodesy, but it was clearly understood that further advances required new generations of instruments, a great deal of money and institutional support. To justify such investment also required compelling objectives.

The cartographic historian Anne Godlewska has advanced the thesis that, during the eighteenth century in Europe, classical geography was a unified discipline: it focused on determining the figure of the earth and national datums for a set of spatial scales, extents, and associated positional accuracies needed for national mapping programmes. Once that task was accomplished, geography diverged into the sub-disciplines of geodesy, cartography, and geography, redefined as written descriptions of regions and places. After that, the history of any one of the disciplines was not necessarily synonymous with the others (Godlewska, 1989). My extension of Godlewska's argument is this: at the very beginning of the Cold War in both the US and the USSR a great re-convergence of the now disparate disciplines of astronomy, geodesy, geography, geology, cartography, photogrammetry, and geophysics occurred at an entirely different suite of spatial scales, extents and accuracies, dictated by the constraints of fighting or precluding nuclear war. This was the central objective of the American geodetic sciences. A remarkable portion of that convergence occurred in Columbus, Ohio.

4. The Geodetic Sciences after the War

After the war's end, Professors Harding, Marshall and Coddington tried again to establish their geodetic project. The Ohio State University they solicited was substantially different from the one they had approached a decade before. The western shores of the Olentangy River were cluttered with hundreds of barracks, instrument labs, and temporary classrooms built to train G.I.s for combat and civilian war industry workers for accelerated production. The distance between Columbus and Dayton, Ohio had not changed, but the relationships between them had. The Army Air Corps had become the Army Air Force, and was about to become the Air Force. Wright Field in Dayton was now the headquarters of the Air Material Command, and was home to the major laboratories and training centres for aerial reconnaissance. Harding now had major connections to the national leadership of military intelligence. A convergence of great significance had begun. In one of the drafty buildings crowded in G.I. Village, the Mapping, Charting and Reconnaissance Laboratories were organised in 1947, soon renamed the Mapping and Charting Research Laboratory (MCRL).

It is unclear from surviving records whether or not Professor Harding and the other founders of the MCRL had any interactions with a chemist named Wallace R. Brode, who had worked at OSU under contract to the Army earlier during the war on infrared filters for reconnaissance systems, a topic closely related to photogrammetry and allied subjects of the MCRL. After the war Brode left OSU to become the first director of scientific intelligence for the new Central Intelligence Agency (CIA), a clandestine assignment masked by his appointment as the Associate Director of the National Bureau of Standards (Doel and Needell, 1997, pp. 64–71, 75). Brode played an important role in establishing post-war American science research policy and structure, precisely because he straddled the border between traditional academic research institutions reoriented to war research, and the new post-war institutions of scientific intelligence. His lasting legacy to the Intelligence Community was his reordering of the CIA's nascent infrastructure of scientific intelligence so that its divisions paralleled university disciplines (Doel and Needell, 1997, p. 64). Brode also addressed the needs and constraints of military and intelligence-funded university researchers attempting to work productively under novel Cold War security protocols.

The records of Brode's last OSU research project contain an extraordinary letter in which Brode advocated the immediate termination of the extant OSURF research contract No. 232, made with the Engineer Board of the Chief of Engineers of the Army, and a new contract signed instead with the Office of Scientific Research and Invention of the Navy. Brode had found the Army contract administrators too restrictive in their prescribed research protocols, yet also inattentive to the potential for unwitting disclosure of research results that could jeopardise national security. The Navy's research office, by contrast, offered relatively unrestricted funds earmarked to specific researchers who designed their own research protocols, and negotiated methods by which research results could be communicated clandestinely to relevant military authorities, using the OSURF as a formal contractual structure that neither directed the research nor was even informed of its results and conclusions. Brode's position is a succinct description of both the functional organisation of the MCRL organised the next year at OSU, and also much of the most important and secret science of the Cold War.[11]

In the case of the MCRL, the governmental contracts that would be the sole financial foundation for the enterprise were coupled to a guiding structure for research based on consultation and review by international geodesists outside the purview of the federal government. 'Upon returning from military service, Professor Harding renewed interest in the geodetic sciences by presenting a formalized plan aimed at meeting the anticipated demands of the profession. The plan for a proposed center was submitted during 1947 to a selection of over thirty world recognized experts for their review and comment. The plan was revised accordingly and efforts were made to secure funds to support the center's development. The first significant funds were offered by government agencies as a means for conducting research into problems which for many years had inhibited the growth of the profession' (Merchant, 1969, p. 1).

The foundational contract of the MRCL, OSURF No.306, was negotiated with the Mapping and Charting Branch, Material Division, of the US Army Air Force at Wright Field in Dayton, Ohio, 'for the purpose of improving, initiating, and developing techniques and equipment essential to photogrammetric and

[11] Wallace R. Brode, letter of 5 July 1946, in OSU Archives RG 38/0/12, part 7. OSURF contract No.232, contracted with Engineer Board, Fort Belvoir, Virginia: 1945–1948.

precise surveying processes necessary to mapping and charting operations'. The contract was classified 'SECRET'.[12] That original contract was soon supplemented by others, in a cascade of contracted research resulting in publications varying in classification level from unclassified to the highest secrecy levels of the US government.[13]

The MCRL's contracted research spanned a wide variety of geodetically-related subjects and technologies.[14] Four specific projects from the earliest period of the lab will give a sense of the breadth of the research, its significant implications for pioneering post-war earth sciences, and its complete integration with Cold War geopolitics. The projects have been reconstructed from the surviving declassified technical reports, in conjunction with the OSURF contract file archives. The level of detail presented varies amongst the projects, reflecting the imperfect archives of documents that have survived.[15]

4.1. The Southern Arizona Controlled Area (1947–1950)

The MCRL, in conjunction with the US Coast and Geodetic Survey, resurveyed and monumented[16] hundreds of specific points in southern Arizona to first-order geodetic accuracies, coupled to adjacent carefully calibrated photo-reconnaissance targets. This network turned southern Arizona into a reconnaissance laboratory, over which virtually every American imagery system has been

[12] OSU Archives RG 38/0/18, part 8. OSURF contract No.306-308, AF AMC, WPAFB contract W33-038-ac-16805.

[13] This continued over the next half century from the MRCL's foundation, and continues to the present. Many specific agencies have contracted with MCRL or its successors, but the great majority of MCRL contracts have been negotiated with the research agencies of the US Air Force.

[14] Characterising contracted research can be problematic, especially in the case of classified contracts. The products of MCRL research can be approached in several ways. Most of the MCRL contracts led to publications, both technical papers published at OSU and a myriad of professional papers based on contracted work. The technical papers were issued at varying classification levels over many years (and often reclassified over time), but research results were sometimes conveyed clandestinely, as will be examined in greater detail in the next section of the paper. The official list of MCRL publications, 'List of Technical Papers issued by the Mapping and Charting Research Laboratory July 1947–May 1959' (supplied to the author by Richard Rapp, OSU), lists titles, authors, and contract numbers for 248 separate reports issued from July 1947 to May 1959. The information for one report has been carefully cut out of the list. There are always interactions between researchers working in a common laboratory, and particularly when working together on projects partially funded by different contracts. The historical documentation of the MCRL research, however, is archived exclusively by specific OSURF contract. I have used MCRL contract reports, published papers, materials from the OSURF contract archives, and interviews to reconstruct MCRL activities.

[15] According to OSU Archives staff, major projects to convert paper records to microfilm and microfiche began in the 1960s. Unfortunately, a good portion of the original microfilm stock proved defective, and the Archives was not able to preserve and convert all the original materials.

[16] 'Monuments' in American geodesy are generally small brass medallions cemented in place at specific points. A geodetic network is an assemblage of monuments and the measurements and errors between them.

flown since, using the precisely-known configurations of the monuments and targets to evaluate and calibrate the cameras or imagery systems.[17]

4.2. Project 307-X (1947–1959)

The second MCRL project was a systematic appraisal of Russian geographic, geodetic, and cartographic materials—possibly from the Hough materials—performed primarily by Dr Nicolai T. Bobrovnikoff, a Russian émigré professor of astrophysics at OSU. Bobrovnikoff had been induced to take a leave of absence from teaching at OSU to concentrate on the Russian materials. Two things were happening. First, the Cold War was growing much colder. The second contract, originally unclassified, was reclassified SECRET on 1 March 1948. Second, investigation of the Russian materials revealed them to be much more significant than originally thought. Bobrovnikoff reached the end of his period of allowable leave under OSU regulations, precipitating a crisis. In response, Harding arranged to increase contract funding immediately to take on Bobrovnikoff full-time at the MCRL, and to hire additional personnel. His letters about the project are illuminating. 'Due to the existing international situation, it seems essential that the work presently being done by Project 307-X be expedited [...]. It has become increasingly evident that both the quality and amount of geodetic and astronomical data essential to chart and map preparation which can be obtained by the project far exceeds our original estimates [...]. The end product of this research is, for your information, being furnished not only to the Air Material Command, but to the Army Map Service of the Corps of Engineers and the Central Intelligence Agency of the State Department'.[18] Over the next decade Bobrovnikoff wrote dozens of MCRL technical reports, at least one of which still remains classified.[19]

4.3. Tying continental datums by solar eclipse (1948)

Teams of MCRL researchers were dispatched, with Army, Navy, and Air Force supporting personnel and facilities, to make simultaneous observations of the solar eclipse of 8–9 May 1948 (they were also dispatched again in 1954) in order to refine the distances and orientations between terrestrially-based national datums. The technique required multiple teams of observers situated along

[17] The earliest report published on the subject was W.O. Byrd, G. Reames, E. Tanck and D. Cooke (1949) 'Arizona Coordinates, Central Zone, and Elevations of Photo Control Points in the Mesa and Phoenix Quadrangles of the Southern Arizona Controlled Area', *MCRL Technical Report* TR (378)-6-61 (October 1949), 33pp. (Contract No. AF 33(038)-3729).

[18] Letter from Harding to Col. Albert C. Foote, Aeronautical Chart Service, USAF, dated 22 April 1948. In OSU Archives RG 38/0/18, part 8. OSURF contract No.306-307, AF AMC, WPAFB contract W33-038-ac-16805.

[19] N. T. Bobrovnikoff (1947) 'Report on Availability in Washington of Russian Publications on Geodesy, Cartography, and Topography', *MCRL Technical Report* TR (307)-5-5 (August 1947), 4 pp. (Title Unclassified–Report SECRET) (Contract No. W33-038-ac-16805).

the path of totality, equipped with very accurate clocks. As the earth's rotation rate is almost constant, the times at which the personnel observed the beginning and end of totality could be used to calculate the distances between the positions of the observers. The purpose of the exercise was clearly stated. 'A trans-ocean long distance measurement between Asia and the Aleutian Islands would be invaluable in tying together the triangulation networks of two continents as well as providing data for determining the figure of the earth. The data resulting from a successful measurement would be most useful in the firing of long range guided missiles'.[20]

4.4. Operation Plumbob (1947–1950)

The research project that was perhaps the culmination of Harding's efforts in the first phase of the MCRL built on developments in higher precision geo-referencing using Shoran electronic distancing equipment systems.[21] Shoran was to be coupled to progress in determining the attitude of reconnaissance camera systems (the camera's orientation relative to the earth).[22] If the position of a plane and its attitude were known with precision, then a photograph from the plane at that moment could be referenced to a geodetic network by finding specific monumented points on the photograph. The geodetic positions of other points found on the photograph could be determined by their distance and direction from known points.

Operation Plumbob flew, but the project was much less successful than predicted. This was principally because photogrammetric positioning of points was well suited for horizontal positioning but poorly suited for vertical positioning. Height is determined relative to the geoid, the equipotential surface of gravitational attraction. Determining the geoid is ultimately a matter of many measurements of gravity. Photogrammetric positioning was therefore less helpful than imagined. As fate would have it, the shape of the geoid was determined by the scientists at OSU—but not by Professor Harding.

5. Crossing the Olentangy River

By 1950, the MCRL was in full flower, with many research contracts under way, led by leading experts in their fields. By definition their mission did not

[20] Report from the Photographic Laboratory, Wright-Patterson Air Force Base, to Headquarters, Air Material Command, dated 13 May 1948. In OSU Archives RG 38/0/18, part 8. OSURF contract No.306-308, AF AMC, WPAFB contract W33-038-ac-16805.

[21] Shoran is a radar technique used for navigation—the name is an acronym for 'Short Range Aid to Navigation'. Essentially, the position of a Shoran receiver is determined by receiving radar waves broadcast from two different Shoran transmitters at known locations. The phase relationships between the received signals can be used to calculate the receiver's position.

[22] Harding, letter to Chief, Air Material Command, dated 1 July 1947. In OSU Archives RG 38/0/18, part 8. OSURF contract No.306-308, AF AMC, WPAFB contract W33-038-ac-16805.

include instruction and training; this was the business of the eastern banks of the river. But the entrepreneurial Harding was not satisfied with this division, and he wrote a proposal to the Council on Instruction of Ohio State University.

The MCRL had been established on the western shore, because it was explicitly a contract lab and not an instructional facility. But once the need for the research had been demonstrated, and the contracts underway, it was a logical step to the additional need to train new people to join and expand the enterprise. Thus Harding proposed that the geodetic enterprise should expand to encompass teaching, which meant the enterprise must cross the river to the campus. Harding therefore proposed that OSU charter an Institute of Geodesy, Photogrammetry and Cartography.

Cold War science constraints are at the heart of his rationale. The need for this work, he wrote, 'has increased sharply in recent years with the mounting demands of civil and military aviation, guided missile research, modern naval operations, mapping of polar regions and many other concerns lately intensified by the critical state of world affairs. These vital practical needs demand geodetic bases, photogrammetric methods, and cartographic techniques far more precise and extensive than any now existing, and they cannot be met without intensive basic research of the type in pure science that must be nurtured in the academic environment or its equivalent. Not only must research be supported for competent men now available, but many more young research workers must be developed, and practitioners trained to apply the results of research'.[23]

The geodetic sciences proposed to cross the Olentangy River on their own terms, in the form of an independent institute under the Graduate School rather than through affiliation with any extant college or department. 'To establish a new department would necessitate direct affiliation with an existing college, and for several reasons this is undesirable. Perhaps the most important reason is that the work embodies elements of pure science, on the one hand, and engineering on the other, that are inextricably interlaced and may not be dissociated if the project is to flourish. Nor may either the theoretical or the practical aspect of the work be emphasized or supported at the expense of the other. To seat the necessary administrative unit squarely in any one of the existing college environments would be to risk its total effectiveness'.[24] In short, there was no useful distinction to be made here between science and engineering, or between 'pure' or 'applied' research. The very nature of the geodetic enterprise would be ill-served by traditional academic departmental structures; Harding insisted on this point.

On 20 November 1950, the Board of Trustees of the University authorised the establishment of the Institute of Geodesy, Photogrammetry, and Cartography (IGPC), to be directed by an Executive Board of six positions, which effectively shared governance powers across traditional campus divides.[25]

[23] Bevis Papers, 'Institute of Geodesy, Photogrammetry, and Cartography, 1950–1955', 'A Proposal for an Institute of Geodesy, Photogrammetry, and Cartography' (n.d.), p. 2.

[24] *Ibid.*, p. 5.

[25] *Ibid.*, p. 6.

Between the MCRL and the new IGPC, the geodetic sciences at OSU now constituted the first graduate degree-granting institution in the geodetic sciences in the western hemisphere. Now Harding needed money. He wrote to OSU officials at all strata, insisting that, if the geodetic enterprise was to work at all, it would have to be supported at far higher levels than the university had envisioned. In a critical letter to the Dean of the Graduate School in 1952, Harding noted that, in the previous five years, the MCRL had already realised 'in excess of $1,200,000, of which there has accrued to the Research Foundation a total of over $320,000' [for administrative overhead]. Harding noted 'it would require an additional $150,000 to put the Institute on a full operating basis (from the standpoint of essential instruments)'. Harding had also lined up major industrial support. 'I am most happy to report that we have assurances from European manufacturers that highly specialized photogrammetric equipment […] will be made available to the University for Institute use on a loan basis through the Mapping and Charting Research Laboratory'.[26]

Harding attempted to persuade his Columbus colleagues just how unique the new Institute was, in the context of international geodesy. Without exception, the great European institutes for instruction and research in geodesy were national institutions, supported by their states. Harding had created an American equivalent of a national geodetic sciences institute, but the basis for its support was ultimately the OSU administration and the whims of the Ohio legislature. Harding pulled no punches. 'Considerable embarrassment will be avoided on the part of the University if the Institute can be placed in a position to "hold its head high", particularly in view of the pointed questions being directed to it from many parts of the globe'.[27]

The geodetic enterprise got the money it demanded, and it purchased or was loaned the finest geodetic and photogrammetric equipment of the era. This now led to conflicts over space on the campus. By 1956, President Bevis was confronted with a request for lab space to be re-allocated to the Institute, in order to utilise equipment secured on long-term loan from the Aerial Reconnaissance Laboratory at Wright Field. 'Unless suitable space is provided, by this summer we shall have the important instruments, valued at $90,000 standing idle', they threatened.[28] For comparison, in 1953 the Department of Geography made an inventory of the entire stock of physical equipment at the department, including maps, furniture, and all instruments. The total value was $16,265.06.[29] The Institute was promptly supplied with additional lab space.

[26] The equipment in question was 'valued at approximately $75,000 (Wild A-7, $55,000 and Wild A-6, $20,000' [both are Swiss-made photogrammetric stereo-plotters]).

[27] Bevis Papers, 'Institute of Geodesy, Photogrammetry, and Cartography, 1950–1955', letter from George Harding to Dean N. Paul Hudson, The Graduate School, 6 January 1952, pp. 2–3.

[28] Bevis Papers, box 20, 'Geodesy, Institute of', letter from Dean James F. Fullerton to President Howard L. Bevis, 19 April 1956.

[29] Bevis Papers, box 20, 'Geography, Department of: Correspondence: 1942, 1953, 1955', Report of Inventory of Geography, 2 February 1953.

Harding's great triumph was to cross the Olentangy River. He had established a laboratory to pursue military and intelligence research, then used the needs and constraints of the laboratory to expand into academic instruction, and then leveraged university funds and precious space on the campus for an degree-granting institute organised outside traditional academic structures, directed to the Cold War research objectives of the US Air Force. Then Harding attempted a greater expansion.

6. The Era of Gravimetric Geodesy

Harding and his colleagues were well on their way to re-making geodetic history, particularly in the successful deployment of a great array of new geodetic technologies. However, as the Dutch geodesist Maarten Hooijberg has noted, the success of the new instruments was based on 'about 150 years of development of theory' (Hooijberg, 1999, p. 4).

In the 1850s, the members of the Great Trigonometrical Survey of India and their leader Sir George Everest discovered that plumb bobs were deflected from the true vertical by the mass of the Himalayas, but the deflection was less than it should have been based on the theoretical mass of the mountains. Plumb bobs by the shore, however, were deflected more than they should have been based on the theoretical mass of the ocean's waters. These anomalies triggered raging debates in geophysics lasting half a century. The mathematician and Archdeacon of Calcutta John Pratt, and George Biddell Airy, Astronomer Royal of the United Kingdom, devised two different hypotheses to account for the mass anomalies, both of which posited that at some unknown depth the weights of the overlying rocks would be the same everywhere. The American geologist Charles Dutton named this concept 'isostasy'. Eventually these ideas became a theory of isostasy that implied that continents and oceans were balanced in equilibrium.[30]

The theory of isostasy became the basic hypothesis of geodesy, and a geodetic infrastructure grew around it. By 1936, the International Association of Geodesy had founded the International Isostatic Institute. The Institute's founding director was Dr Weikko Heiskanen (1895–1971), who was simultaneously Professor of Geodesy and Director of the Finnish Institute of Technology. Heiskanen and his institutions were amongst many geodesists expanding the traditional principal objective of geodesy, which was the positioning of specific points on or near the earth's surface, and the shape and size of the Earth, to comprehend 'in cooperation with other earth sciences, the interior structure of the earth'.[31] Heiskanen and F.A. Vening Meinesz, the inventor of the submarine gravity apparatus, were generally considered the world's greatest

[30] For a thorough presentation of these matters, see Oreskes (1999).
[31] Weikko Heiskanen, opening remarks delivered at the symposium 'Geodesy in the Space Age' (6 February 1961). Published in Laurila and Heiskanen (eds) (1962), pp. 2–3.

living geodesists. In 1950, on behalf of the MCRL, Harding invited Heiskanen to take a sabbatical from Finland to visit Columbus, Ohio.

Heiskanen's arrival signified a major new era in geodetic progress at OSU, in fact an interdisciplinary convergence, in Anne Godlewska's definition (Godlewska, 1989). The principal factors in this were the development of a cascade of new classes of geodetic instruments (Warner, forthcoming) coupled to major advances in computational machines and massive investments by military and intelligence agencies. The OSU geodetic scientists adapted their research directions and emphases to parallel and guide the Cold War strategic objectives. It was, after all, these objectives which justified the major part of the funding that underwrote their activities.

Heiskanen was essential to the establishment of the IGPC for two reasons. First, his impeccable credentials and international stature and connections could draw first-class teachers and researchers to the Ohio campus. Second, he had a compelling project: to determine the global geoid by the gravimetric method, and to adjust the major continental and national datums to the geoid to create a World Geodetic System. Harding and Heiskanen reached an understanding. Together they would attempt the defining project of international geodesy in the twentieth century, and they would persuade the US Air Force to fund it. Heiskanen took leaves of absence from both Finnish institutes he directed, and moved to Columbus to become the first scientific director of the IGPC, with Harding as the administrative director.

In 1951, the MCRL and IGPC crafted 'A Preliminary Proposal for the Immediate Assembling, Processing, and Utilization of World Gravity Data'.[32] The proposal was the culmination of a variety of exercises previously performed by the MCRL on the earlier Air Force contracts.[33] The document is a landmark in the integration of emerging earth science and Cold War objectives. The following excerpts from the document convey how the geodetic enterprise melded geopolitics and geodesy.

The major objective of the proposal was to determine the global conformation of the geoid, by determining geoidal heights (separations between the geoidal surface and the reference ellipsoid, based on Stokes' basic method) and deflections of the vertical (geoidal undulations relative to the ellipsoid, calculated by an improvement on Stokes' method devised by Vening Meinesz) measured and calculated for a globe-spanning network of points (Goad and Mueller, 1993).

[32] OSU Archives RG 38/0/34, 'World Gravity Data', OSURF No.504, Air Force Cambridge Research Center, AF19(604)287: 1951–1957.

[33] *Ibid.*, p. 1. The proposal itself particularly identifies the following MCRL technical reports as foundational: No.88, Mr W.O. Byrd, 'The Firing of Missiles without the Necessity for Reducing World Geodetic Data to One Datum', 1950; No.111, Dr Walter G. Lambert, 'The Spheroid of Reference, the Geoid, and Stokes' Method for Determining the Relation between Them', 3 November 1950; No.118, Dr W. Heiskanen, 'World Gravity Needs for Geodetic Purposes', 3 November 1950; No.124, Dr W. Heiskanen, 'The Geodetic Significance of World Wide Gravity Studies', 15 November 1950.

The preliminary proposal is perhaps the seminal document generated by the geodetic sciences at OSU. It proposed a budget of $150,000 per year to assemble, correct, and correlate global gravity data over a period of three years. The major project goals explicitly merge the strategic objectives of Cold War weapons systems and the research frontiers of twentieth century astrophysics and geophysics.

> This information is essential for, and makes possible the following geodetic achievements: A. The accurate determination of the size of the earth from triangulation surveys, and the placement of all geodetic control of the world on a common datum. B. The determination of accurate terrestrial baselines for the purpose of establishing absolute distances between the celestial bodies of the universe. C. A more direct method for determining the distances and directions of long lines essential to certain types of long range guided missile navigation [...] 2. Another major end result of the project would be the vast increase in geophysical knowledge concerning the crustal materials of the earth. Many geophysical studies would be greatly aided by the results of this project.[34]

In other words, for the same investment DOD could realise ICBM guidance, fundamental data for the mechanisms of crustal processes, calculation of interstellar distances, and a global datum based on the earth's geoid.

The plan of attack was to assemble an unprecedented data set. 'Gravity data and the necessary small scale topographic and bathymetric maps would be assembled from every possible known and available source in the world. Such sources include government agencies, scientific institutes, private exploration companies and intelligence agencies'.[35] Beyond extant data to be collated, there were the major lacunae. These were addressed: scientists already working with the Navy, such as Columbia's seismologist Maurice Ewing, could expand their efforts over the deep oceans. 'The weak point is the expanse of ocean. However, our Navy has submarines and they take practice cruises. In the past these submarines have carried observers trained by [Maurice] Ewing of Columbia University to use the Vening Meinesz apparatus for determining gravity at sea. Hitherto their work has been mostly off shore to continue seaward certain gravity profiles of interest to geologists. But there is no reason why gravity observations should not be made in midocean and at wherever gravity data are most needed'.[36]

The gravity proposal was apparently written collectively, but it contains perhaps a hint of Harding's power waning, Heiskanen's waxing. The appeal to the military significance of the global gravity project is now coy, contrasting with Harding's previously direct manner.[37] 'Recent history suggests that such

[34] *Ibid*., pp. 1–2.
[35] *Ibid*., p. 4.
[36] *Ibid*., p. 6. See also Oreskes (1994) and Oreskes (1999).
[37] The proposal itself lists no authors, but the cover letter to the proposal was signed by Harding, Heiskanen, and several other officials of OSU.

a unified geodetic datum has a rather special interest for our armed forces and for the national defense. The Office of Naval Research sponsors and assists various scientific enterprises, some of them matters of basic research, with no immediate applications in sight. What lay behind the sponsorship and substantial assistance given by the Office of Naval Research to the work of [George] Woollard, [Maurice] Ewing and their coadjutors in determining gravity on land and sea it would be presumptuous to affirm with too great positiveness. But it may be suspected that behind the evident scientific interest of these operations the Office of Naval Research glimpsed something of possible military value'.[38] Or, as was more candidly stated by the former OSU professor Wallace R. Brode, 'the majority of all our basic science programs are supported by military agencies as an altruistic gesture but with hidden motives'.[39] Or in some cases not so hidden.

The first response to the Preliminary Proposal by Air Force contracting staff at the Cambridge Research Center was modest. The Air Force proposed the contract be classified 'Confidential', that it be less than global in scope, much more geopolitically focused, and that it cost less money. The objectives of the Air Force were:

> 1. Assemble gravity data from all available sources. Particular effort is to be made to obtain the maximum possible data for the Eurasiatic continent. 2. Carry out a critical evaluation of processing and reduction methods for the purpose of determining the optimum procedures to be used in the application of the gravity data to the determination of the undulations of the geoid and the deflections of the vertical. 3. Apply the methods developed under 2 above to the mapping of deflections of the vertical in Eurasia east of the line Leningrad–Moscow–Stalingrad with the maximum accuracy consistent with the density of the available data.[40]

The responses of the OSU geodetic sciences to the Air Force's offer go to the heart of the processes of Cold War knowledge production. The response letter, written by Paul Pepper, the research coordinator of the MCRL, objected that the budget was too low, and that they could only consider beginning the work concentrating on Eurasia 'with the expectation that as funds become available the contract will be modified or a new contract written to cover additional work extending the scope to bring it more in keeping with that outlined in the Preliminary Proposal'.[41]

[38] *Ibid*., p. 11.
[39] Wallace R. Brode to John A. Armitage, country desk officer, USSR, State Dept., n.d. [July 1959]. Box 6 of 11, Papers of Wallace R. Brode. As quoted in Doel and Needell (1997), p. 75.
[40] OSURF Records (see footnote 32) 'Contract for Research Directed Toward the "Application of Gravity data to the Determination of the Geoid in Eurasia"', p. 1.
[41] OSURF Records, 'World Gravity Data' (see footnote 32), letter from Paul N. Pepper, MCRL, to Commanding General, Air Force Cambridge Research Center, 2 November 1951.

The scientists objected to the classification of the project, but suggested a way to accomplish exactly what the Air Force wanted by other means.

> We request [... that] this contract be worded so that the Statement of Work makes no special reference to the Eurasiatic continent nor to the specific line [Leningrad–Moscow–Stalingrad] [...]. In this connection, we believe that any reports publishing data of a general, geographically wide-spread character would not require classification even though they might include incidentally some data on high priority areas. On the other hand, we should expect that any report or communication singling out and referring primarily and specifically to the high priority regions should be classified 'Confidential'.

Here was the crux of Cold War compromise. The scientists would do the work specified, without saying that was what they were doing.

Scientists defended their position by noting that classification would hinder the participation of international collaborators: 'It might be remarked that in gathering the data needed for this program, the cooperation of many foreign nationals is required, and it is impossible to obtain this cooperation to the extent that is necessary to advance this program effectively if the project is to retain a high classification. We believe that the interests of the Air Force will best be served by keeping this program unclassified except for the specific items pointed out above'.[42] In short, the scientists would find a way to give the Air Force exactly what it wanted, while maintaining the open protocols of international geodesy.

The Air Force was convinced. On 17 March 1953 the Air Force dispatched Supplement No. 1 to the proposed contract, increasing the first-year award by $60,000, and changing the statement of work to: '1. Assemble gravity data from all available sources. Particular effort will be made to obtain the maximum possible data for areas designated by the Contracting Officer [...] 3. Apply the methods developed under 2 above to the mapping of the deflections of the vertical in accordance with specific priorities of areas as designated by the Project Officer'.[43] The supplemental contract, as amended, was the first installment in OSU gravity research contracts that continued for the duration of the twentieth century, and are not yet completed. Leningrad, Moscow, and Stalingrad had disappeared from view, but they were still very much in sight.

The interchange between the Air Force and the MCRL over the gravity contract is a paradigm of the processes, mechanisms, and subterfuges of the earth sciences in the Cold War. Note that neither party disagreed with the nature and scope of the work to be done. The entire question, for both parties, was how to disguise the contract objectives, given the disparate constraints of

[42] OSURF Records, 'World Gravity Data' (see footnote 32), letter from Paul N. Pepper, MCRL, to Commanding General, Air Force Cambridge Research Center, 12 December 1952.

[43] OSURF Records, 'World Gravity Data' (see footnote 32), letter from Raymond S. Bugno, OSURF Administrative Assistant, to Dr George H. Harding, 17 March 1953.

the Air Force on the one hand and prominent international civilian scientists linked to global scientific unions on the other. They found a way to do just that.

The gravity contract shepherded by Harding was his legacy to the geodetic sciences at OSU, but there were increasing conflicts with Heiskanen. On 30 June 1953, Harding resigned from the University, and then disappeared from the OSU geodetic sciences enterprise that he had created. He may have returned to intelligence work.[44]

Heiskanen became primary director of the geodetic sciences, assisted by leading European geodesists Dr H. A. Hirvonen, Dr T. J. Kukkamaki, Dr Bertil Hallert, and Dr F. A. Vening Meinesz, who rotated positions between various Finnish and other institutions to maintain research and instruction in the burgeoning programme. The Institute had shared facilities in the original MCRL barracks on the western side of the Olentangy River, but courses in subjects other than geodesy and photogrammetry were taught on the campus proper, on the eastern shore. Geodesist Clair E. Ewing, one of the new generation of students, noted the spatial difficulties presented by the expanding geodetic sciences programme straddling the curricular and extra-curricular sides of the river.[45]

The preliminary world gravity data proposal was realised in parts, and classified surreptitiously. By very different means, a similar Cold War accommodation was realised in the programme of photogrammetric research, the next major section of the geodetic enterprise to develop.

7. Hidden in Plain Sight: The Quest for Analytical Photogrammetry

Photogrammetry at OSU as part of the geodetic enterprise began with the foundation of the MCRL. Harding was joined by Dr Earl Church from Syracuse University, considered the leading photogrammetrist of his era. At the beginning of the era of the Institute, the geodetic enterprise hired Dr Frederic J. Doyle, a rising star and student of Church. Doyle had worked in strategic targeting reconnaissance and cartography in the Army Air Force in the Second World War. After the war he pursued graduate studies in photogrammetry in Europe before his arrival in Columbus. Doyle's career with the OSU geodetic

[44] The evidence for this is entirely circumstantial. Following his departure from Columbus in 1953, Harding disappeared from the *Scientific Citation Index*. Harding died in 1962. *The Columbus Dispatch* wrote: 'At the time of his death, he was serving as a consultant with the public administration service in Kabul, Afghanistan' (29 June 1962). [Obituary included in Dr Harding's faculty file, OSU Archives].

[45] Ewing (1956). Ewing noted that: 'The Institute is presently housed in World War II barracks across the Olentangy River northwest of the campus. The geodesy and photogrammetry courses are held there while all other courses are on the campus […]. The problem of commuting between the Institute and the campus is frustrating to say the least. Parking facilities at OSU are practically nil and it is impossible to break away from a class, drive several miles, search for a parking space and get into another class in ten minutes. This has often caused students to drop desirable classes' (p. 60).

sciences would link the Ohio institutions to reconnaissance projects, particularly spaceborne reconnaissance. Doyle's cameras and photogrammetric systems would run the gamut from the most visible of civilian NASA sensors to the deepest intelligence secrets of the US government.

Photogrammetry is the science of deduction of dimensions and spatial relationships of points, features, and objects in images, particularly in photographs. The science dates back to the Renaissance systems for rendering perspective by mechanical means, so photogrammetry long preceded aerial photography. By the middle of the twentieth century, however, photogrammetry was almost synonymous with the examination of sets of overlapping photographs of the earth obtained from aircraft. A variety of types of mechanical instruments, such as comparators, plotters, rectifiers, and radial mensuration devices had been developed to aid and expand applications of aerial photography. Fundamentally, these were grounded on arranging stereopairs of photographs by hand and eye.

Doyle's great quest was the perfection of what he called 'analytical photogrammetry'. By this he meant substitution of computational systems for mechanical composition. '*Every attempt at improving the accuracy of aerial triangulation results in increasing the proportion of computational to instrumental work*', he wrote. 'The question immediately arises, "Why not take the bull by the horns, and use a completely analytical system?" [...] Given an opportunity for development, it does not seem unreasonable to expect that before many years, precise analytical aerotriangulation may be capable of establishing first order control any place in the world' (Doyle, 1953; emphasis in original).

In Doyle's vision, first order photogrammetric control converges with first order geodetic control, as photogrammetry and geodesy in general converge, because both sciences are concerned with precise positioning of specific points. Just as the Air Force prioritised assembling gravity data and computing deflection of the vertical for the Eurasiatic continent east of the line Leningrad–Moscow–Stalingrad, so also the Air Force (and the rest of the DOD and the Intelligence Community) had specific priorities for where to establish first order control. Not surprisingly, those priorities were in the same part of Eurasia where OSU geodetic sciences were already deployed.

In 1955, retired Colonel Richard S. Leghorn, a specialist in photo-reconnaissance with extensive experience at the Air Force Photogrammetry Lab at Wright-Patterson Air Force Base, proposed that NATO and the Warsaw Pact nations could conduct mutual, bi-lateral aerial reconnaissance of each other to preclude surprise attack and allow both sides to prepare against the weapons systems they actually faced. He projected his plan into the nascent space era. 'And we might announce a start on construction of a reconnaissance earth satellite, the transmitted results from which we would be willing to turn over to a U.N. inspection agency' (Leghorn, 1955). Leghorn's proposal, renamed 'Open Skies', was proposed by President Eisenhower at a summit conference in Geneva. It was summarily rejected by the Soviet Union, and also bitterly opposed by elements within the US Joint Chiefs of Staff. Nevertheless, apart from the proposal to turn imagery over to the United Nations, the US and the Soviet Union proceeded to implement Leghorn's proposal, but at the deepest levels of secrecy. On the US side, the Intelligence Community developed clandestine projects to create novel reconnaissance platforms. The CIA first created GENETRIX, a programme of high-altitude reconnaissance balloons lofted over the Soviet Union. Then, the CIA developed project AQUATONE, better known as the U-2. Finally, the CIA—with major assistance from OSU—created CORONA.

8. Columbus, Ohio, and CORONA

The fundamental changes that would revolutionise photogrammetry and cartography were a combination of improvements in cameras and film, and major developments in the intricate technologies for image rectification, mensuration, triangulation, and comparison, with both coupled to the training of a new generation of specialists. The latter technologies and their skilled practitioners were extremely expensive. With Harding out of the picture, Heiskanen and Doyle together assumed leadership of the geodetic sciences and the search for additional funds to advance research.

In 1955, they made a major overture for massive funding of photogrammetric and cartographic equipment to improve the capabilities of the Institute. Their proposal to OSU played on Cold War anxieties. 'Throughout the world there exists an immediate and continuing demand by both military and civilian agencies for additional knowledge of the physical conditions of the earth we live on. The fundamental expressions of this information are found in aerial photography, topographic and geologic maps, geodetic and geophysical data. President Eisenhower's proposal at Geneva to use aerial photography for checking on military installations is only one example of the importance of this type of information […]. In spite of widespread recognition of their importance, there exists a tremendous gap between the requirements for, and the production of, photographs, maps, and charts […] there are two fundamental causes for this discrepancy between supply and demand: (1) The lack of personnel trained in the arts and sciences involved in modern map making procedures […] (2) The lack of an adequate technology for producing map information efficiently. Despite the fact that *the advances in mapping sciences within the last two decades have exceeded those of the preceding two centuries*, there exist tremendous unexplored potentialities in the application of electronic data-gathering, information theory and automation, to the techniques of map production'.[46]

President Bevis opened the OSU purse strings again. Money and the latest in technologies flowed into the geodetic sciences, and an entire generation of OSU-trained geodesists, geophysicists photogrammetrists, and cartographers

[46] Bevis Papers, Box 21, 'Institute of Geodesy, Photogrammetry, and Cartography, 1950–1955', letter from W. A. Heiskanen and Frederick J. Doyle to President Bevis, 11 October 1955 (emphasis added).

flowed out, populating new departments of geodetic sciences in the US and abroad.[47] The new generation trained at OSU populated greatly expanded federal geodetic and cartographic research and production agencies, including DOD agencies like the Army Map Service, the Office of the Chief of Engineers of the Army, the Air Force Aeronautical, Charting, and Information Center, and the Navy Hydrographic Office. They also enlisted in a shadowy assemblage of intelligence labs and facilities already consolidating into what would later be named the National Photographic Interpretation Center, the National Reconnaissance Office, the Defense Intelligence Agency, and the CIA Directorate of Science and Technology. Between those directly instructed at OSU and those who participated in the regular series of OSU geodetic conferences, there is probably not a single significant geodetic or photogrammetric specialist from the western bloc who did not spend time in Columbus during the 1950s. Most of those trained at OSU moved on, the next generation of educators was recruited from within. These included Uhro Uotila, Richard Rapp and Ivan Mueller, all of whom entered as graduate students and eventually became department chairs.

The quickening pace of events inside and outside Columbus, Ohio during the late 1950s linked geodetic and photogrammetric progress to prospects in space. The so-called 'Sputnik Crisis' in American science policy has recently been extensively re-examined. There is significant material derived from declassified sources that suggest the need for a reinterpretation of the view that President Eisenhower's strategic science policies were caught by surprise by the success of the Soviet space programme.[48] Certainly activities proceeded more rapidly in the wake of Sputnik, but they advanced in directions long anticipated and advocated by Eisenhower's strategic scientific advisors.

There were three specific federal actions taken in 1958 with enormous consequences for the subsequent fate of the geodetic enterprise at OSU. First, the DOD formed the Advanced Research Projects Administration (ARPA) to consolidate and organise the disparate research and development infrastructures of the different military services and the Intelligence Community.

Second, a classified but publicly acknowledged Air Force reconnaissance satellite and photogrammetric applications project called WS-117L was abruptly cancelled—and then secretly reconstituted by the CIA as CORONA.[49]

[47] One example is OSU graduate Richard K. Burkard, who wrote *Geodesy for the Layman*, possibly the single most important English-language publication in the history of geodetic literature. The first edition was published in 1959. Many anonymous writers and editors have contributed to subsequent editions. The book has never been out of print. The version I consulted is: *Geodesy for the Layman*, 5th edn (Washington, DC: Defense Mapping Agency. *DMA Technical Report* 80-003, December 1983). A digital version of the publication is available at the website of the National Imagery and Mapping Agency: http://www.nima.mil.

[48] See especially Hall (1995).

[49] CORONA was declassified in November, 1995. In short order, four books on the system appeared, three the products of CORONA-related symposiums, the other written by an author long associated with publication on reconnaissance and other classified satellite systems: Ruffner (1995), Peebles (1997), McDonald (1997) and Day *et al.* (1998).

Finally, and least well known, the OSU geodetic sciences negotiated a special programme through the Air Force Aeronautical Charting and Information Center (ACIC) in St. Louis, Missouri. Under this programme, special students enrolled at OSU for intensive and specialised courses in geodesy and photogrammetry, outside the normal graduate programme and its constraints. From OSU, they returned without advanced degrees to ACIC or a wide variety of federal agencies and clandestine organisations.

Activities at OSU increased frenetically. Total advanced graduate student participation in courses doubled from 1957 to 1958, and doubled again in 1959.[50] In hindsight, however, the confluence of these events—the establishment of ARPA, the secret reconstitution of CORONA, and the ACIC special programme—set the stage for the great decline of the OSU geodetic sciences.

A major consolidation and transformation of the geodetic enterprise occurred in the spring of 1959. The MCRL, Harding's great legacy, was discontinued. Further outside-contracted research was administered directly through the OSURF. The academic teaching and research functions of the enterprise were reformed into a new Division of Geodetic Science within the Department of Geology, as an interim step towards the establishment of a Department of Geodetic Sciences. Doyle was named Chairman of the Division. He lasted only one academic quarter. Heiskanen responded to Doyle's rising power essentially the same way as he had reacted to Harding's leadership almost a decade earlier. Doyle resigned from the faculty of OSU in early 1960. Robert Oetjen, the Associate Dean of the College of Letters and Sciences replaced Doyle as Acting Chairman of the new Division. Heiskanen continued as director of the IGPC, but the Institute's role was changed, 'now primarily concerned with the conduct and promotion of research across interdepartmental lines' (Merchant, 1969, p. 6).

9. Isostasy and the Geodetic Revolution from Space

The roles of the OSU geodetic sciences changed ever more swiftly as the new generation of geodesists and photogrammetrists trained in Columbus established themselves in other universities, and other research enterprises, particularly classified federal programmes, grew. Heiskanen's great goal of a unified, mass-centred global datum was to be realised—but not by Heiskanen's geodetic sciences programme directly, nor by the gravimetric methods he had long championed.

Satellite geodesy as it developed was a logical extension of gravimetric geodesy, and had been anticipated by members of the OSU geodetic sciences before Sputnik I was launched on 4 October 1957. However, the implementation

[50] Enrollment figures from OSU Archives, College of Letters and Science, Office of the Dean, RG 24/a/7, 'Geodetic Science, 1955–1962'.

of satellite applications was transformed by a fortuitous discovery. C. G. Weiffenbach and W. H. Guier of the Applied Physics Lab (APL) of Johns Hopkins University recorded radio transmissions from Sputnik I, and measured the Doppler shift in the signal as the satellite passed overhead. They determined that, if one knew the geodetic position from which the signal was recorded, and made certain assumptions about the earth's mass, the Doppler shift could be used to derive the characteristics of the satellite's orbit. One could calculate the satellite's Keplerian elements.

F. T. McClure of APL discovered that an extraordinary inversion was possible. If the orbits of a satellite could be determined with sufficient accuracy, then the Doppler shift of radio transmissions from the satellite as received at an unknown location, in conjunction with radio signals also received at the unknown location from ground-based stations of known location, could be combined to derive the actual location of the unknown position (Hooijberg, 1999, p. 3). The implications of this discovery were enormous. It opened the world, particularly the world's oceans, to electronic positioning. The first implementation of the discovery was the Navy's NAVSAT, also named the Navy Navigation Satellite System (NNSS), but most commonly referred to as the Transit navigational satellite system (Stansell, 1971). The accuracy of the positioning was critically dependent on the accuracy of the determination of the satellites' positions. This accelerated research on satellites' motion as affected by the earth's gravity fields at very high elevation—and also the closely related subject of ICBMs and gravity at high elevation.

Early in the post-Sputnik era, in 1961, the OSU geodetic sciences organised a symposium, 'Geodesy in the Space Age', to explore these new developments.[51] Preliminary analysis of data from the pioneering Sputnik, Explorer, Vanguard and Discoverer [the cover name for CORONA] satellites indicated there were substantial low-order harmonic variations in the earth's gravitational field—a violation of the basic hypothesis of isostasy! As geodesist John O'Keene noted in 1978: 'The Vanguard results swept this whole philosophy into limbo. Stress differences clearly existed in the mantle. Isostasy was clearly not true on a large scale, at least not to the extent demanded by the Basic Hypothesis of Geodesy. The meaning of this revolution in geodesy is not yet clear'.[52]

The results from satellite geodesy undermined the fundamental concept that a global geoid could be constructed by Heiskanen's gravimetric method, which had been based explicitly on the isostatic hypothesis.

The implications of the fall of isostasy can be seen clearly in the case of Heiskanen, who had left his original research on deep-earth structure and isostatic equilibrium behind. In Heiskanen's last update to his Curriculum Vitae in 1965, he expressed the shift directly: 'Former research field: Astronomy,

[51] Simo L. Laurila and W. A. Heiskanen (1962).

[52] Letter by John O'Keene to Homer Newell, 22 June 1978, commenting on a draft version of Newell's manuscript. Quoted in H. E. Newell (1981), p. 199.

Isostasy, Inner Structure of the Earth, Size and Shape of the Earth, Triangulation, City Surveying. Present research field: Physical Geodesy, Dimensions of the Earth and of the Sphero- and Geopotential Surface Above it, Geometric and Gravimetric Constants of the Earth, Gravity Anomaly Field of the Earth and at any Elevations Above It'.[53] In other words, Heiskanen the European isostasist had become a specialist in gravimetric techniques applied to physical geodesy, and from there to non-isostatic geodesy, which happened to be the geodesy of ICBMs and reconnaissance satellites.

The new satellite-derived data sets now available were critical additions to ground-based positioning and gravity data sets being assembled towards Heiskanen's goal, the World Geodetic System. In 1960, research efforts of the Army, Navy, and Air Force were combined to create the World Geodetic System of 1960 (WGS1960), based on a combination of surface gravity data, astro-geodetic data, and Shoran and Hiran geo-positioning surveys to obtain a best-fitting ellipsoid for the most significant datum areas (Hooijberg, 1999, p. 44).

In 1966, the Department of Defense formed a World Geodetic System Committee to develop an improved WGS, based on greater surface data and increasing volumes of satellite data. The satellite data came from the Navy's TRANSIT Doppler navigation system and from four different programmes of optical geodetic satellites. These four geodetic satellite systems reflected a growing separation between civilian-accessible and classified programmes; this was a distinct change from the more fluid and negotiable classification protocols in force a decade or two earlier. At the beginning of the OSU gravity work in 1951, Harding and Heiskanen had successfully redefined the scientific organisation of the contract and also the classification protocols that would control the work. Less than a decade later, security procedures had become more rigid, and were defined by DOD and the Intelligence Community with much less civilian influence.

10. Cold War Knowledge Production and the Shuttered Box

The tensions between the civilian geodetic community, particularly in relation to their larger international constituency and the local DOD and the Intelligence Community, were apparent in negotiations over one of the earlier geodetic satellite programmes, ANNA (Army-Navy-NASA-Air Force). The NASA chief scientist Homer Newell noted that the controversy over data classification 'forced a decision very much like apartheid. It was finally agreed that the scientific geodetic program would continue, with open publication of results on the NASA side. Likewise, the DoD program would continue, and when appropriate the two agencies would cooperate, as with the ANNA

[53] Weikko A. Heiskanen, OSU Archives, Faculty Reports.

satellite. But DoD would decide unilaterally on the disposition and data and results from its part of the program' (Newell, 1981, pp. 118–119).

The contentious data sets being assembled and organised were fundamental to the DOD World Geodetic System of 1972 (WGS 72), the real embodiment of Heiskanen's goal of a global datum. Doppler data from DOD and non-DOD satellite systems were the major space-related data sources. They were combined with other satellite data, surface gravity field data derived from direct observations and interpolations, astrogeodetic deflections of the vertical calculated for points in various national datums, eight terrestrial long line precise traverses, and other sources to produce the Unified WGS Solution, a large-scale least squares adjustment to the previous version of the WGS.[54]

WGS 72 was applied to a variety of tasks, widely varying in security classification. Amongst the most secure applications were the projects within the DOD and the Intelligence Community to locate, position, map and evaluate strategic sites across the planet. The major source for the observational data was the CORONA satellites, the system that had contributed to the data sets used for WGS 72, but was also critically dependent on WGS 72 as the geo-referencing system used to position the reconnaissance targets observed in CORONA photography.

Ironically, a key role in the integration of WGS 72 and CORONA was played by Frederick J. Doyle. After his abrupt departure from OSU in 1960, he had been unemployed less than a month. He first joined Broadview Research Corporation, where he was director of Intelligence Systems Division, 'responsible for research on the interpretation of records from advanced military reconnaissance systems'. The following year, he joined Autometric Inc. as Chief Scientist, responsible for 'design investigations, performance analysis, and specification of ground data reduction procedures for photographic and radar systems combined with position and attitude sensors for mapping and reconnaissance from conventional and hyper-altitude vehicles'.[55] Not until 1995, when the CORONA system was declassified, could it be revealed that Autometric Inc. was a CIA contractor serving as systems integrator for the geodetic and mapping camera systems and application configurations of the CORONA and subsequent classified reconnaissance systems. Doyle had become chief photogrammetrist of the most deeply secret intelligence enterprise in the history of the United States.

The extraordinary secrecy mechanisms devised for CORONA and allied reconnaissance systems had far-reaching implications for university-based research programmes everywhere, and especially at OSU. There was no absolute separation between civilian and classified research—the geodetic sciences had

[54] *Geodesy for the Layman* (see footnote 47), pp. 72–77.

[55] Frederick J. Doyle, Curriculum Vitae, 1970, as presented in an appendix to the letter dated 17 February 1970, from William Pecora, Director, US Geological Survey, recommending Doyle's admission to membership in the Cosmos Club, Washington, DC. OSU Archives, College of Mathematical and Physical Sciences RG 27/a/5 'Geodetic Science: 1968–1974', Accession 93/94.

been masters at prosecuting classified research without obvious signals the work was classified, as in the original gravity contract. But the protocols of the new secrecy triggered even more elaborate patterns of clandestine scientific exchange. I have characterised these patterns elsewhere as a model of Cold War and post-Cold War knowledge production called 'The Shuttered Box' (Cloud and Clarke, 1999). The name is a modification of the metaphor of the 'black box', commonly used in discussions of modern science and technology.[56] The box in this case is the set of elaborate mechanisms that both separates and coordinates classified and unclassified constituencies.

Fundamental progress in the Cold War sciences has been based on the fact that the box has shutters; i.e. that mechanisms have been devised to allow people, money, ideas, and technologies to pass through, while preserving the separations between the constituencies. An example of this model in action at OSU is the Ph.D. dissertation of Army Major Alfred B. Devereaux Jr. (1972). The dissertation topic was 'the feasibility of employing a hypothetical panoramic-frame camera system in aerial triangulation'—in other words, an extension of Doyle's goal of 'precise analytical aerotriangulation […] capable of establishing first order control any place in the world', written two decades earlier. Examination of the dissertation clearly reveals the 'hypothetical camera system' to be a simplified version of the CORONA Advanced KH-4B camera system, integrating high resolution scanning paroramic camera strip photographs with a lower resolution geo-referenced index photograph. Devereaux was awarded a Ph.D. for a publicly accessible dissertation based on one of the deepest secrets of the nation at the time.

The combination of the rigorous programme of instruction of the geodetic sciences and the military-structured needs of its primary student clientele, led to deep structural problems in the geodetic sciences. Chief among these were student recruitment, a problem that was anticipated as early as 1972: 'The graduate program enrollment is dependent upon a non-traditional mix of graduate students—with the vast majority of the current 55 graduate students pursuing an advanced degree coming here, not directly from other universities, but being sent here by branches of the military service, the Department of Defense and foreign governments […]. The graduate students […] have only a restricted time period of 18 months, imposed by the various institutions, to complete a Master of Science and 3 years to complete a Master of Science and Doctor of Philosophy degree […]. These time limits are not realistic. […] In the future it is highly likely that fewer and fewer organizations and governments will send students to Ohio State […].'[57] Matriculation was longer at OSU than in other US schools because most of the faculty were European and there was

[56] For paradigmatic examples, see MacKenzie (1990), Latour and Woolgar (1979) and Latour (1987).

[57] 'Policy and Standards Review, Geodetic Science Department', (Autumn 1972: 2–3). OSU Archives, College of Mathematical and Physical Sciences, RG 27/a/5, 'Geodetic Science: 1968–1974', Accession 93/94.

much more emphasis on the theoretical foundations of geodesy. Since the students were mainly military men on short release times, conflict and strain was inevitable.

The student enrollment did decline, as did the geodetic sciences, which were now established completely on the eastern bank of the Olentangy River, the long-sought goal. As a department, geodetic sciences' funding was now based much more on 'hard money' institutional support through the OSU administration, and much less on 'soft money' contracted through the OSURF. The fact that Heiskanen had driven off such vigorous securers of major innovative military-funded research as Harding and Doyle was also a factor in the programme's senescence. This made the department more susceptible to inter-departmental and inter-college political and funding shifts and priorities.

The geodetic sciences eyed surveying as a possible new source of students, although that violated a promise acting Chair Robert Oetjen had made in 1961: 'I will do all in my power to see that every possible conflict is resolved in accordance with the principle that it will be the function of the Department of Geodetic Science to further the basic science area and it will be the function of the Department of Civil Engineering to further the area of applications'.[58]

The response from Civil Engineering was swift. 'It appears that the Department of Geodetic Science has initiated a new venture by adding a professor who is an engineer to develop new engineering courses and a curriculum which should be in engineering without consultation or cooperation with Civil Engineering. *In other words, to counteract a declining enrollment, geodetic science has moved unilaterally into the civil engineering field*'. Civil Engineering would deal with this threat by devouring it. '[T]he civil engineering faculty considered the proposal for the unification of surveying and mapping efforts [...]. This proposal would combine civil engineering and geodetic science into one department in the College of Engineering. The faculty formally voted to endorse the April 6, 1973 proposal'.[59] Civil Engineering acquired the geodetic sciences, although that story is beyond the scope of this paper.

11. Columbus in Context

For a very critical time in the early and middle Cold War, the fulcrum of western geodetic research was located in Columbus, Ohio, and the progress realised there became the arena upon which the Cold War was prosecuted. A generation of international geodesists was trained at OSU. The Earth Model developed at OSU (and elsewhere) allowed ICBMs to be accurately targeted.

[58] Robert A. Oetjen, letter to Professor Hamilton Gray, 11 January 1961. OSU Archives, College of Arts and Science, Office of the Dean, RG 24/a/7, 'Geodetic Science, 1955–1962'.

[59] Dean Harold A. Bolz, letter to Dr Albert J. Kuhn, Chairman, Council on Academic Affairs, 17 October 1973. OSU Archives, College of Arts and Science, Office of the Dean, RG 27/a/5, 'Geodetic Science, 1972–1973', Accession 93/94 (emphasis added).

However, the revolution in reconnaissance and positioning allowed ICBM launch sites to be detected and geo-referenced by space-borne systems. The capabilities of the latter have thus far precluded the use of the former. That is probably the greatest legacy of the geodetic sciences. Since the middle 1960s all treaties curtailing or reducing nuclear weapons and their delivery systems have specified that treaty compliance and enforcement are to be based on 'National Technical Means', which is to say, CORONA and its successors, and the equivalent Soviet and Russian systems.[60]

The DOD still supports an updated World Geodetic System as its Figure of the Earth, but the international geodetic community, returning to pre-Cold War cooperative protocols, now maintains a more accurate Figure of the Earth appropriate to the geo-referencing precision necessary to measure continental drift. This Figure of the Earth has two conceptual and institutional components: the International Terrestrial Reference Frame, the static portion of the Earth Model, coupled to the cosmos by the wonderfully named International Earth Rotation Service.

The geodetic sciences at OSU during the Cold War are an example of the model of post-war American science characterised by historian Stuart Leslie as the Military-Industrial-Academic-Complex (MIAC) (Leslie, 1992). However, the enterprise differed significantly from most previously described scientific institutions, particularly the great applied physics laboratories created for the Second World War and re-purposed for the Cold War.[61]

When the geodetic sciences did successfully begin at OSU, they did so in a distinctly post-war context, from the very beginning situating their science in the context of Cold War geopolitics and funding sources. Geodetic science research was not based on specific technologies, but instead the integration of many technologies organised across many disparate disciplines, using data sets acquired from and shared with an international community of geodesists. At the same time, from the beginning the leaders of the OSU geodetic sciences embraced classified contracts, and played an active and ambitious role in devising research filtering mechanisms that would comply with not only the research and dissemination protocols of the broad international geodetic community and the academic culture of the university, but also the Cold War strategic security restrictions of the US government. They were far less successful in this than they had hoped.

There are two main reasons for this partial failure. The first is that the OSU geodetic sciences assayed goals that were too sweeping and ultimately contradictory. The members were completely dependent on outside contracted research funding from the DOD and Intelligence Community, with many Cold

[60] A pioneering account of reconnaissance capabilities and their impact in moderating the Cold War arms race is Garthoff (1980).

[61] MacKenzie (1990), Leslie (1992), Dennis (1991) and Dennis (1994). Major references to the Harvard–Boston University–Itek optics enterprise are contained in the CORONA sources (see footnote 49).

War geopolitical strings attached. At the same time, over decades they moved across the river to the campus, opposite to the direction of movement of most other labs. They transformed themselves into members of a traditional academic department, subject to the rules of Ohio State University and the larger scholarly world. The OSU geodetic scientists were candidly discreet in their interactions with the larger geodetic community and the larger community of the university, but discreetly candid with their Air Force research sponsors. Both styles of interaction 'worked' in the immediate moment, but selective disclosure had its price, once the classified contracts dried up.

A second reason for the partial success of the OSU geodetic sciences researchers is paradoxical: they succeeded too well. They formed in a critical moment in Cold War history, organised to attempt the heroic goal of devising the modern Figure of the Earth, at the suites of scales, extents, and accuracies necessary to prosecute or prevent nuclear war. They reached that goal. Their achievement was one of the most important intellectual triumphs of the Cold War, but also perhaps the least apparent. The fruits of the Figure of the Earth are intangible and dispersed. They are distributed across society, embedded in a myriad of technologies, resident in every map or GPS receiver. Once the Figure of the Earth is ubiquitous, it becomes invisible. Over the course of the Cold War, the members of the OSU geodetic sciences community positioned themselves with extraordinary precision along the Olentangy River, and in doing so, they made themselves all but disappear.

Acknowledgements—I am very grateful for financial support from: (1) an NSF Dissertation Improvement Grant through the Science and Technology Studies Program, 'The Cold War, Position, and Gravity: The World Geodetic System and the Sociotechnological Evolution of Geodesy from Space' (NSF SBR-9811930); (2) a Smithsonian Institution Pre-Doctoral Fellowship at the National Museum of American History, Dr Deborah Jean Warner, Advisor, Geodetic Counselor, and Hostess with the Mostess; and (3) an OSU Department of Geography Colloquium Fellowship, courtesy of Department Chair Lawrence Brown; (4) the kind offices of Dr Joel Morrison, Director of the Center for Mapping at the Ohio State University; and (5) a travel grant from the Society for the History of Technology, which got me most of the way to Columbus, Ohio. Special thanks to the OSU interviewees, especially Richard Rapp, Ivan Mueller, Uhro Uotila, Dean Merchant, and John Bossler. Very special thanks to the excellent staff of the Ohio State University Archives, especially Bertha Ihnat and Tamar Chute.

References

Cloud, J. and Clarke, K. C. (1999) 'Through a Shutter Darkly: The Tangled Relationships between Civilian, Military and Intelligence Remote Sensing in the Early U.S. Space Program', in Judith Reppy (ed.), *Secrecy and Knowledge Production* (Ithaca, NY: Cornell University Peace Studies Program, Occasional Paper No. 23).

Day, D. A., Logsdon, J. M. and Latell, B. (eds) (1998) *Eye in the Sky: The Story of the CORONA Spy Satellites* (Washington, DC: Smithsonian Institution Press).

Dennis, M. A. (1991) 'A Change of State: The Political Culture of Technical Practice at the MIT Instrumentation Laboratory and the Johns Hopkins University Applied Physics Laboratory, 1930–1945', unpublished Ph.D. dissertation, Johns Hopkins University.

Dennis, M. A. (1994) 'Our First Line of Defense': Two University Laboratories in the Postwar American State', *Isis* **85,** No. 9, 427–455.
Devereaux, A. B., Jr. (1972) 'Investigations into the Feasibility of Employing a Hypothetical Panoramic-Frame Camera System in Aerial Triangulation', unpublished Ph.D. dissertation (OSU Department of Geodetic Sciences, Dean Merchant, Ph.D. Advisor, 1972). OSU Mathematics and Sciences Library, Theses and Dissertations.
Dille, J. (1958) 'The Missile-Era Race to Chart the Earth', *Life* **44** (No. 19, 12 May 1958), 124–139.
Doel, R. E. (1997a) 'Scientists as Policymakers, Advisors, and Intelligence Agents: Linking Contemporary Diplomatic History with the History of Contemporary Science', in Sonderqvist (ed.), pp. 215–244.
Doel, R. E. (1997b) 'The Earth Sciences and Geophysics', in J. Krige and D. Pestre (eds), *Science in the Twentieth Century* (Australia: Harwood Academic Publishers), pp. 391–416.
Doel, R. E. and Needell, A. A. (1997) 'Science, Scientists, and the CIA: Balancing International Ideals, National Needs, and Professional Opportunities', in Jeffrey-Jones and Andrew (eds), pp. 59–81.
Doyle, F. J. (1953) 'Futuramic Photogrammetry', *Photogrammetric Engineering* **19,** (No. 5, December 1953), 741, 745.
Ewing, C. E. (1956) 'Training Ground for Surveyors and Mappers', *Bulletin Geodesique* **40,** 57–61.
Foreman, P. (1987) 'Behind Quantum Electronics: National Security as Basis for Physical Research in the United States, 1940–1960', *Historical Studies in the Physical and Biological Sciences* **18,** 149–229.
Foreman, P. (1997) 'Recent Science: Late-Modern and Post-Modern', in Th. Sonderqvist (ed.), pp. 179–213.
Galison, P. (1998) 'Physics between War and Peace', in E. Mendelson, M. Roe Smith and P. Weingart (eds), *Science, Technology and the Military* (Boston: Kluwer Academic Press), pp. 47–85.
Garthoff, R. L. (1980) 'Banning the Bomb in Outer Space', *International Security* **5,** No. 3 (Winter 1980): 25–40.
Gimbel, J. (1990) *Science, Technology, and Reparations: Exploitation and Plunder in Postwar Germany* (Stanford: Stanford University Press).
Goad, C. C. and Mueller, I. I. (1993) 'Geodesy', in *Encyclopedia of Applied Physics* (New York: VCH Publishers), **7,** pp. 89–107.
Godlewska, A. (1989) 'Traditions, Crisis, and the New Paradigms in the Rise of the Modern French Discipline of Geography 1760–1850', *Annals of the Association of American Geographers* **79,** 192–213.
Hall, R. C. (1995) 'The Eisenhower Administration and the Cold War: Framing American Astronautics to Serve National Security', *Prologue* **27** (Spring 1995), 59–72.
Hooijberg, M. (1999) *Practical Geodesy* (Amsterdam: Springer).
Jeffrey-Jones, Rh. and Andrew, Ch. (1997) (eds) *Eternal Vigilance? 50 Years of the CIA* (London: Frank Cass).
Keyles, D. (1990) 'Cold War and Hot Physics: Science, Security, and the American State, 1945–1956', *Historical Studies in the Physical and Biological Sciences* **20,** 239–264.
Lasby, C. G. (1971) *Project Paperclip: German Scientists and the Cold War* (New York: Atheneum Press).
Latour, B. (1987) *Science in Action: How to Follow Scientists and Engineers Through Society* (Cambridge, MA: Harvard University Press).
Latour, B. and Woolgar, S. (1979) *Laboratory Life: The Construction of Social Facts* (Princeton, NJ: Princeton University Press).
Laurila, S. L. and Heiskanen, W. A. (1962) *Proceedings of* '*Geodesy in the Space Age*' (Columbus, OH: Ohio State University, Department of Geodetic Sciences).

Leghorn, R. S. (1955) 'U.S. Can Photograph Russia from the Air Now: Planes Available, Equipment on Hand, Techniques Set', *U.S. News & World Report* (5 August 1955), 70–75.
Leslie, S. W. (1992) *The Cold War and American Science: The Military-Industrial-Academic-Complex at MIT and Stanford* (New York: Columbia University Press).
MacKenzie, D. (1990) *Inventing Accuracy: An Historical Sociology of Nuclear Missile Guidance* (Cambridge, MA: MIT Press).
Matthias, J. and Ciesla, B. (1996) *Technology Transfer out of Germany after 1945* (Australia: Harwood Academic Publishers).
McDonald, R. A. (ed.) (1997) *CORONA: Between the Sun and the Earth. The First NRO Reconnaissance Eye in Space* (Bethesda, MD: The American Society for Photogrammetry and Remote Sensing).
Merchant, D. (1969) 'History of the Department of Geodetic Sciences at Ohio State University', in *The Ohio State University Centennial Histories*, College of Physical Sciences (Columbus, OH: Ohio State University).
Moellering, H. (1991) 'Cartography at Ohio State University', *Cartography and Geographic Information Systems* **18,** 210–214.
Newell, H. E. (1981) *Beyond the Atmosphere: Early Years of Space Science: NASA History Series, SP-4211* (Washington, DC: NASA Scientific and Technical Information Branch).
Oreskes, N. (1994) 'Weighing the Earth from a Submarine: The Gravity Measurement Cruise of the U.S.S. S-21', in G. Good (ed.), 'The Earth, the Heavens, and the Carnegie Institution of Washington', *History of Geophysics 5* (Washington DC: American Geophysical Union), pp. 53–68.
Oreskes, N. (1999) *The Rejection of Continental Drift: Theory and Method in American Earth Science* (New York: Oxford University Press).
Peebles, C. (1997) *The CORONA Project: America's First Spy Satellites* (Annapolis, MD: Naval Institute Press).
Richelson, J. T. (1997) 'The Wizards of Langley: The CIA's Directorate of Science and Technology', in Jeffrey-Jones and Andrew (eds), pp. 82–103.
Ruffner, K. C. (ed.) (1995) *CORONA: America's First Satellite Program* (Washington, DC: Center for the Study of Intelligence, the Central Intelligence Agency).
Schweber, S. S. (1991) 'Big Science in Context: Cornell and MIT', in P. Galison and B. Hevly (eds), *Big Science: The Growth of Large-Scale Research* (Palo Alto: Stanford University Press), pp. 149–183.
Smith, G.-H. and Taaffe, E. J. (1969) 'History of the Department of Geography', in *The Ohio State University Centennial Histories*, College of Social and Behavioral Sciences (Columbus, OH: Ohio State University), Part 1.
Sonderqvist, Th. (ed.) (1997) *The Historiography of Contemporary Science and Technology* (Amsterdam: Harwood Academic Press).
Speiker, E. M. (1969) 'History of the Department of Geology', in *The Ohio State University Centennial Histories*, College of Social and Behavioral Sciences (Columbus, OH: Ohio State University), Part 1.
Stansell, Th. A., Jr. (1971) 'Transit, the Navy Navigation Satellite', *Navigation* **18,** No.1 (Spring 1971), 93–109.
Warner, D. J. (forthcoming) 'From Tennessee to Timbuktu: Cold War Efforts to Measure Intercontinental Distances', *Historical Studies in the Physical Sciences*.