American Cartographic Transformations during the Cold War

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ABSTRACT: A great convergence of cartography, secrecy, and power occurred during the Cold War. In the American case, a complex series of interactions between secret and classified programs and institutions and their publicly accessible counterparts accomplished both traditional and novel objectives of military geographic intelligence. This process also yielded the World Geodetic System, a mass-centered "figure of the earth" at accuracies adequate for warfare with intercontinental ballistic missiles. A structural and institutional separation developed between enterprises charged with overhead data acquisition systems, which were classified at increasingly high levels of secrecy, and those responsible for data reduction, analysis, and mapping systems, which remained largely unclassified and publicly accessible, in part to conceal the classified data acquisition systems. This structural separation destabilized photogrammetric mapping by displacing systems that privileged dimensional stability with systems that privileged novel sensor types more appropriate to Cold War geo-political objectives and constraints. Eventually, photogrammetric mapping systems were re-stabilized by successfully implementing analytical solutions imposed in digital mapping and data management systems. This achievement re-privileged dimensional stability, now redefined to the new media of geo-referenced digital data. In the early 1970s these developments culminated in advanced research projects of Military Geographic Intelligence Systems (MGIS). Their deployment in the Vietnam War was both their apex and their undoing. In the aftermath, classified mapping and database systems diverged from civilian versions of MGIS, which became known as Geographic Information Systems (GIS).

KEYWORDS: Military geographic information; panoramic cameras; terrain analysis; World Geodetic System; analytical solutions; photogrammetry; Intelligence Community; Cold War; Vietnam War; Military-Industrial-Academic Complex; Talent-Keyhole; Corona; data acquisition; data reduction

Cartography, Secrecy, and Power

Most of the fundamental technologies of contemporary American cartography were devised in the last half of the twentieth century and shaped by the exigencies and opportunities of the Cold War. The technologies and their data sources were often secret, at least initially. The organizations that developed and used these technologies evolved from classified programs to increasingly unclassified and accessible enterprises. This essay explores the histories of three closely related suites of geo-spatial sciences and technologies and their applications:

- The technologies for extending geodetic control and geo-positioning, which culminated in the World Geodetic System (WGS) terrestrial reference frame and its associated technologies for accurate point positioning and targeting;
- The rapidly evolving technologies of photogrammetry and overhead observation, the latter variously termed reconnaissance, earth-resource surveys, and finally remote sensing; and
- National and international mapping programs of the U.S. military and intelligence community during the period between the Korean War and the Vietnam War, with particular regard to the convergence of geo-positioning, photogrammetry, and observation systems, which culminated in projects of Military Geographic Intelligence Systems (MGIS).

Three critical themes organize the disparate enterprises, programs, and objectives of this great endeavor. The first of these is the complex relationship between cartography and secrecy. It has been argued that cartography is primarily a form of political discourse concerned with the acquisition and maintenance of power (Harley 2001, p. 85). Harley analyzed early modern maps and their "silences," which were both intentional and epistemological. The Cold War was prosecuted by a complex array of institutions and programs with differing access to secret data. In the American case, an intelligence organization is designated as such because it possesses the legal authority to

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classify and declassify information. Intelligence at a certain level of classification can be SECRET[1], but one of the major themes of this story is that by no means were American secrets confined to intelligence organizations. Instead, a complex and quite productive ethnography of exchanges between unclassified, declassified, and classified programs and institutions evolved in spite of, and to some extent precisely because of, the division between them. These exchanges culminated in a system, still in place, in which the products of highly classified technologies are displayed candidly as completely unclassified maps and data, a process that renders the entire map a kind of "silence" insofar as the map effectively conceals its secret roots as it reveals that secret's fruits.

The second major theme is the reconfiguration of the geo-spatial sciences in their entirety, which was both the trigger and the ultimate product of this interplay of cartography and secrecy. Cartographic historians addressing different historical eras have used disparate terms to describe these recurrent configurations and their distinctly different yet related characteristics. Forbes (1980) described the milieu of eighteenth-century "mathematical cosmography" from which emerged Edney's (1993) complex amalgam of nineteenth-century cartographic *modes*. Similarly, Godlewska (1989; 1997, p. 24) has identified a scientific *divergence* that occurred in the late eighteenth century after the successful realization of western European national-level mapping programs. Once the objectives of the mapping programs had been substantially realized and they no longer occupied the frontiers of research, the unified discipline of geography split into the disciplines of geodesy, cartography, and geography, now redefined as written descriptions of regions and states. Godlewska notes that, from the divergence onwards, the specific histories of the disciplines were not synonymous with each other. I argue that a great *re-convergence* of these disciplines occurred during the Cold War, at the suites of spatial scales, extents, and tolerances necessary to either wage or prevent nuclear war. This convergence was a relatively short but enormously productive period of technological innovation coupled to major advances in geographical theory, concentrated in the 1950s and 1960s. In the decades that followed, the enriched sub-disciplines that participated in the convergence diverged again.

The third theme of the essay is that of power and its own undoing. This accounts for the subsequent divergence of the geo-spatial disciplines once again, and also for the confounding of their Cold War origins that is at the heart of the incomplete and often erroneous histories that dominate contemporary American cartography and geographic information science. The great Cold War geo-spatial convergence was designed to fight nuclear war but also to preclude it. In obligatory and, therefore, ironic collaboration with the parallel cartographic enterprise in the Soviet Union, the geo-spatial convergence prevented global war for nearly half a century; that was and is its greatest triumph. The deployment of the American geo-spatial convergence in hot war, particularly in Vietnam, led to its undoing.

Prelude: American Cartography in 1944

In 1944 the first nuclear bomb had not yet been detonated at Alamagordo, New Mexico, and the systematic dismantling of German science and technology by Allied and Soviet forces had only just begun. On that eve, what was the status of the interconnected systems for geo-positioning, overhead observation, and systematic mapping?

World War II was a global conflict fought with national maps based on different map datums and different reference ellipsoids. The demands of weapons systems like bombers and missiles with vastly increased ranges made the mismatches between national mapping systems quite evident. One solution to the problem was to expand national datums to include the territory of other nations, but in 1944 this presented enormous technical and political challenges. Extending first-order geodetic control for any geodetic network required incremental advances at the edge of the network in question and a physical presence on the surface for at least the instant that any given geodetic point was "occupied." Without exception, the technologies for point geo-positioning by any other means were insufficiently accurate to allow geodetic control to be extended beyond the boundaries of the network. However, SHORAN (*Sho*rt *Ra*nge *N*avigation) radio navigation systems, devised around 1943 for approximate geo-positioning for "blind-bombing" missions, held

[1] In the American Intelligence Community, SECRET, TOP SECRET, and even more highly classified CODEWORD programs are indicated by the obligatory full capitalization of their names at all times. In this essay the programs will be capitalized that way only initially, to indicate that they were (or remain) classified. Full capitalization will be dropped for subsequent uses of the word, lest the text appear like a kidnapper's ransom note.

1944	HOUGHTEAM dispatched to the European Theatre, SHORAN developed for blind bombing missions
1946	First postwar nuclear bombs exploded in Operations Crossroads
1947	Mapping and Charting Research Laboratory (MCRL) established at Ohio State University (OSU); Air Force separates form the Army, Central Intelligence Agency (CIA) established; nominal Cold War begins.
1951	Institute of Geodesy, Photogrammetry, and Cartography (IGPC) established at Ohio State University
1954	U-2 Program begins, Spatial Resolution Target built at Fort Huachuca, Arizona
1955	President Eisenhower proposes "Open Skies" Program, which is rejected
1956	International Geophysical Year (IGY) declared for 1957-1958
1957	The Soviet Union launches Sputnik I
1958	National Aeronautics and Space Administration (NASA) established; Advanced Research Projects Agency (ARPA) established; Air Force WS 117-L cancelled [and reconstituted secretly as CORONA]
1959	First series of "Special Students" from Air Force Aeronautical Charting and Information Center (ACIC) arrives at OSU;, Army World Geodetic Datum (WGD59) finished
1960	First successful CORONA mission; Francis Gary Powers and U-2 shot down over Soviet Union; RACOMS Program begins
1961	Bay of Pigs invasion; TALENT-KEYHOLE security protocols formalized; National Reconnaissance Office (NRO) established
1962	Cuban Missile Crisis; first successful CORONA-ARGON mission; first "advanced" CORONA KH-4 mission
1963	President Kennedy assassinated; Lyndon B. Johnson becomes President of the United States
1964	Album "Meet the Beatles" released
1965	Significant escalation of the wars in Vietnam and Laos; a secret DOD study suggests applications of classified reconnaissance by nominally civilian federal agencies
1966	USGS begins Building E-1 at new National Mapping Division (NMD) center in Reston, Virginia
1967	Six-Day War, Soviet invasion of Czechoslovakia; first CORONA KH-4B mission; Outer Space Treaty signed
1968	First color films flown in CORONA missions; Civilian Applications Committee (CAC) formed
1969	Strategic Arms Limitation Talks (SALT) begin in Finland; Apollo 11 astronauts reach the Moon; MGIS Program begins
1971	First HEXAGON reconnaissance satellite mission
1972	Last CORONA mission; SALT treaty signed; World Geodetic System of 1972 (WGS72) completed; most DOD and IC service-level mapping and geodesy agencies consolidated into the Defense Mapping Agency (DMA)
1973	Office of Management and the Budget (OMB) Federal Mapping Task Force report advocates major consolidations of federal mapping and geodetic efforts
1975	Vietnam War ends
1978	President Jimmy Carter first publicly acknowledges that the U.S. employs satellite reconnaissance
1992	National Reconnaissance Office (NRO) is officially acknowledged to exist; William Jefferson Clinton elected President
1995	Authorization for the declassification of CORONA; the Civil Applications Committee (CAC) is acknowledged to exist

Table 1. Chronology of events.

great potential for geo-positioning outside extant geodetic networks and were recognized as powerful tools for post-war development (Henry 1946; Lorenz 1946; Warner 2000). (See Table 1 for the chronology of tool development.)

Aerial photography from airplanes was one of the triumphant technologies of World War I, and aerial photogrammetric mapping applications blossomed between the wars. Aerial photogrammetry was vital in World War II, but applications were limited to a few important tasks. Major extensions of national-scale mapping programs using photogrammetric stereo-models at national-program map accuracy standards all but halted during the war—there was extensive use of photogrammetry for quick, less accurate surveys of actual or potential combat areas but, generally, the war was fought by all sides using extant, largely pre-war map bases and maps, either previously secured or captured from the enemy (Doyle 1998). The major applications of aerial photography were in reconnaissance, particularly for bombing missions, and tactical battlefield strategy.

Amrom Katz (1948), a photogrammetric specialist whose career extends through this entire story, estimated that about 80 percent of the information secured on the Axis powers and their activities during World War II resulted from aerial reconnaissance. One of the most important uses of aerial photography for battlefield strategy was to aid the construction of three-dimensional terrain models at various scales (see Pearson, this issue), which were used in almost all major offensive operations (Spooner 1948, p. 513). Construction and use of such terrain models was a principal task for *military geography*, and planning and analysis derived from the use of the models were examples of *military geographic intelligence*, or MGI (Ayers 1998). Data sources for MGI included a wide array of types of information, ranging from captured maps and historic scientific data to the revolutionary products of new sensors developed for the war effort, particularly false-color infrared film and radar. New types of photography were so numerous that Katz (1948, pp. 589-90) developed a new typology of their applications by distinguishing instrumentation photography used to record fleeting impressions (as from radar screens) from photographic instrumentation used for direct recordings of phenomena (such as atomic bomb blasts and V-2 flight paths) for subsequent detailed analysis.

Before World War II, federal civilian and military mapping programs were supposedly distinct but complexly interrelated, particularly because many civilian agencies had inherited their programs from previous military efforts. With the war, the entire infrastructure of American cartography, including academic personnel and universities as well as civilian and military mapping personnel and institutions, was mobilized. This was likely the greatest transformation in the history of American cartography, with far-reaching, long-lasting, and sometimes counterintuitive impacts. The story that follows springs directly from the consequences of that mobilization in the early stages of what was to become the Military-Industrial-Academic-Complex (MIAC) (Leslie 1992).

"The Problem of Obtaining Information through Obscurity"

American scientific and technical mobilization for the Second World War was accompanied by broad adoption of compartmentalized security systems and secrecy protocols, the origins of which lie in pre-war corporate intelligence systems (Dennis 1987; 1997). Examination of the re-organizing impact of secrecy systems on American science and technology has focused primarily on the weapons labs developed domestically for the war, and the subsequent Cold War (Dennis 1994; Dennis in press; Doel 1997; Forman 1987; Kevles 1990; Leslie 1992; MacKenzie 1990). Another important subject has been the mobilization of Allied scientific intelligence directed abroad for the war effort, particularly through the Office of Strategic Services (OSS), the predecessor of the Central Intelligence Agency (CIA). The labs and foreign intelligence converged at the end of the war in the systematic dismantling of German science and technology by the western Allies on one side, and the forces of the Soviet Union and its eastern allies on the other (Gimble 1990; Matthias and Ciesla 1996). Most analysis of this bifurcated technology transfer between the East and the West concerned German science and technology directly applicable to weapons systems, particularly the V-2 rocket (DeVorkin 1992). A parallel transfer of German earth science data and technologies, still little known or analyzed, changed the course of American cartography in the Cold War.

In October 1944, U.S. Army geodesist Floyd Hough was dispatched to Europe along with eighteen men and three women specialists, who collectively comprised the secret HOUGHTEAM, a special unit of the Military Intelligence Division of the Office of the Chief of Engineers of the Army. Over the next year, operating freely throughout the European Theatre but in close collaboration with many other elements of Allied Intelligence, the Houghteam captured vast quantities of cartographic and photogrammetric equipment, map series at all scales, and geodetic and cartographic data. They also secured "a nucleus of German geodesists and mathematicians who were removed to the U.S. Army Area of Occupation (i.e., away from the Soviet Union-controlled area) for use on scientific projects of the U.S. forces" (Hough 1950, p. 4)). After sharing and distributing collections with other intelligence units, they shipped a total of 90 tons of captured materials back to the Army Map Service in Washington, D.C. The German Materials, as they came to be called, diffused into both classified and accessible civilian applications in American geodesy, photogrammetry, and cartography for the next quarter century (Clarke and Cloud 2000; Cloud 2000). Although much of the cartographic and photogrammetric material was described and analyzed in the relevant professional literature (Reagan 1945; Wilson 1946; Brandt 1948), many of the other parts of the German Materials remained secret and restricted.

These distinctions in access resulted from an evolving system of secrecy protocols that are the equivalent, for the American earth sciences, of the security protocols developed during World War II for the great weapons labs. The security protocols for earth science applications are related to, but distinct from, those in force for the more "strategic" weapons systems and their allied technologies. The principal objective in classifying any system is to safeguard the technology and its capabilities. Data associated with the technology need be secret only to the extent that the data disclose the system. In the case of sophisticated weapons systems, for example, data associated with them may not have other applications. Data important to the earth sciences are very different. While data acquisition and management systems might be classified, potential alternative applications for cartographic data from a classified map may be numerous. Alternatively, data from an unclassified map might prove to be strategically important in another context. Therefore, the strategic commerce of secret geographic and cartographic knowledge differs fundamentally from other kinds of secrets.

This structural ambiguity, inherent in MGI, runs through the history of American cartography in the Cold War. In 1953, Paige Truesdell of the U.S. Navy Photographic Interpretation Center read a paper titled "Report of the Unclassified Military Terrain Studies Section" as a part of the Report of the Photo Interpretation Committee to the American Society of Photogrammetry in Washington, D.C. He began:

> A subject heading such as this is almost meaningless for the various military agencies. With few if any exceptions all terrain studies carry a security information classification of some kind. The members of this section have investigated their respective agencies and to the best of their knowledge there are no unclassified military terrain studies. *In a few instances they do however have some associated projects that may be of interest* (Truesdell 1953, p. 468; emphasis added).

Truesdell then proceeded to list and describe studies on a variety of subjects, including "vegetation type interpretation using aerial photography," and "the study of Antarctic surface features by photogeographical methods," followed by three pages describing his own work on agricultural crop disease identification using infrared photography. All the studies were and remain relevant to many earth sciences, all were and remain unclassified, and all stood slightly adjacent to closely related but classified projects produced by the same personnel with the same equipment and same data. This duality and the tension associated with it persisted for the next half century and continue today.

The Cold War careers of Amrom Katz, a photogrammetrist and systems developer, and Richard Leghorn, a pilot, aerial photographer, and instrument designer, exemplify the complex ethnography of secrecy and disclosure, as well as the movement back and forth across the barriers of classification. Both were principal photogrammetric scientists in Operation Crossroads, the first nuclear bomb experiments after Hiroshima and Nagasaki. Diverse photogrammetric instruments were used to capture details of the explosions, an exercise Katz called "the most outstanding single example of complete use of photography, and, as noted, a preview of things to come" (1948, p. 590). Amongst those previews of things to come left unstated by Katz was the fact that during Bravo Test, the first underwater detonation of a nuclear bomb, the company of 20,000 personnel assembled in the Marshall Islands for Operations Crossroads was thoroughly contaminated by radioactive materials. The final test bomb was cancelled, and all personnel were sworn to secrecy and dispersed (Weisgall 1994). Both Katz and Leghorn returned thoroughly convinced that nuclear war was, at least locally, not survivable. For Leghorn, that left two stances against the Soviet Union, based on the assumption that the Soviet Union would eventually have nuclear weapons as well. The first was mutual forbearance and negotiated peace as an alternative to mutually assured destruction, the policy in force to the present day. The second was to remove the enemy in a pre-emptive nuclear strike. Both options would require superb reconnaissance. Leghorn noted "for these reasons it is extraordinarily important *that means of long-range aerial reconnaissance be devised that cannot be detected"* (1946, p. 55; emphasis added). Hence, even seemingly innocuous vegetation studies might remain classified in order to conceal sensor capabilities.

Both Katz and Leghorn spent their professional lives involved in the dualities of secrecy and disclosure inherent in observation systems that are vital, yet cannot be detected and should never be revealed. Leghorn retired from the Army Air Force to privatize the Boston University Optical Research Laboratory into the Itek Corporation, which has designed the optics of virtually every U.S. classified reconnaissance system. Katz was also at the heart of every early American reconnaissance system. In 1949, Katz and Leghorn were named to a committee to "conduct a survey of the electro-magnetic spectrum from the point of view of its applicability to reconnaissance" (Panel on Cartography and Geodesy 1949, p. 19). That enterprise was part of the larger secret project for "Development of Methods, Techniques and Equipment for Obtaining Information through Obscurity." "Obscurity" has two different meanings here. The first is that intended by the staff of the Joint Research and Development Board: the relative absence of light and atmospheric clarity. The specific directive of the secret committee was to develop such reconnaissance tools as radar imaging and flash photography for nighttime and clouded observation. But "obscurity" also describes the process by which scientific and technical advantage could be both gained and disguised, and also be distributed and utilized effectively across the entire range of American civilian, military, and intelligence institutions.

The methods devised to push and pull information "through obscurity" included public disclosure of certain technologies and data, situated immediately adjacent to deeply guarded secrets. Much of the German Materials captured by the Houghteam were publicly disclosed immediately after the war, and other materials were eventually disclosed following declassification. Even so, other treasures found in Europe were never publicly revealed for the next half-century—including the fact that on April 17, 1945, the Houghteam had located the geodetic archives of the German Army in a remote warehouse in Saalfeld, a discovery that would change the course of the Cold War (Hough 1950, p. 2).

Deflecting the Vertical

Cold War geodesy is critical to any treatment of Cold War cartography because there was a geodetic revolution that underlies, literally, all subsequent cartographic developments. One generation after the end of World War II, national and continental datums were connected, the Earth-Moon system was discerned, and global geodesy was reconfigured by the development of mass-centered datums, which are now the basis for all precise geo-referencing in earth science. The first of these mass-centered datums was the World Geodetic System (WGS) of the U.S. Department of Defense, arguably one of the most important American intellectual achievements of the Cold War (Warner 2002).

The processes by which the WGS was created epitomize the secret/disclosed protocols of knowledge production. In 1946 the Army Corps of Engineers established the Inter-American Geodetic Survey (IAGS), which was directed to create continental-scaled geodetic networks and comprehensive mapping programs "in foreign areas whose governments were friendly to the U.S." (Robertson1955, p. 450). Very different organizations were founded for geodetic work in—or over—the much greater fraction of the Earth's surface inhabited by unfriendly governments.

Fundamental to the latter enterprise was the founding in 1947 of the Mapping and Charting Research Laboratory at Ohio State University (OSU). Within a few years of its foundation the laboratory had recruited one of the largest and most productive corps of geodetic and allied scientists on the planet. The enterprise was funded almost entirely by the Air Force, which initially wanted to restrict the research to classified contracts. The leaders of the laboratory countered that such classification would discourage the foreign participation essential to their work. They proposed, instead, a system of unclassified research contracts that could quietly yield classified reports on demand (Cloud 2000).

The laboratory and its successor OSU institutions were particularly strong in gravimetry and photogrammetry. Laboratory staff developed seminal texts and methods (Burkard 1959) and trained the next generation of world geodesists, who later populated geodetic research institutions and government laboratories throughout the world.

The new geodesists used a cascade of new technologies, many with military roots. A family of electronic distance measuring devices (EDMDs) evolved from the Shoran navigation system of World War II (Sennert 1946; Warner 2000). The EDMDs were first used to improve the accuracies of local geodetic networks during the re-surveys adjacent to the Atlantic Missile Range at Cape Canaveral, Florida, and the Pacific Missile Range at Vandenberg Air Force Base, California, in order to situate new ballistics cameras critical to the testing of intercontinental ballistic missiles. The first successful program to "tie-in" an isolated island archipelago to continental datums with first-order geodetic precision addressed the Caribbean islands downrange from Cape Canaveral. Another isolated archipelago, the nuclear test zone of the Marshall Islands in the western Pacific Ocean, was tied in to the North American Datum by coordinated use of an array of techniques, including lunar occultation and gravimetric methods. The shift to a mass-centered global datum was the culmination of an international intellectual endeavor that spanned at least two centuries but was completed in several decades during the Cold War because a mass-centered "figure of the earth" was critical to the successful deployment of satellites in near-earth orbit and the successful targeting of intercontinental ballistic missiles. With reference to American cartography, the principal consequences of these geodetic advances were the extension of successively more accurate and extensive geo-referencing frames, in two and then, later, three dimensions, coupled with increasing abilities to geo-reference specific points with tolerable accuracy even if those points were not adjacent to extant geodetic networks. The eventual goal of these enterprises was to provide accurate geo-positioning of any point, anywhere on earth.

Very Important Points

A major reason that the German Materials captured by the Houghteam were so important was that the data included not only first-order geodetic surveys by the German Army deep within the Soviet Union on the Eastern Front, but also first-order geodetic surveys stretching through the very heart of "Denied Territory," the vast inaccessible regions of the Communist Bloc nations. The latter surveys resulted from contracts performed by German geodesists early in the twentieth century to locate potential routes for the Trans-Siberian Railroad (Daugherty 1995). These geodetic tracings formed the primitive skeleton of the densified geodetic networks covering Eurasia, which would be required to effectively geo-reference salient points in the Soviet Union and Eastern Europe. Most of the landmass of Eurasia was effectively off limits to the extension of American geodetic control by both traditional and novel ground-based technologies used for piecewise expansion of extant geodetic networks.

The geo-political isolation of this vast surface area induced the U.S. government to fund varied research projects that would lead to methods that extended geodetic control by photogrammetric means. Geodesy and photogrammetry always converge eventually, in that both endeavors are fundamentally concerned with the configurations of the very specific positions of very specific points, be they points on the ground or points on an image, or both (Merchant 1998). But the photogrammetry that would eventually provide the extension of this geodetic control was to be based on imagery from systems "that cannot be detected," in Leghorn's (1946, p. 47) words. And so it was that the convergence of geodesy, photogrammetry, and cartography at the heart of this story took place at the highest levels of secrecy in the history of the United States.

Through several decades of "black" programs, the CIA devised a methodology for developing overhead imagery sensors and their allied technologies. "Black" programs encompass many endeavors, but for this discussion the important point is that CIA imagery acquisition programs involved small numbers of sole-source contractors cleared into top-secret codeword compartmentalized security domains and paid in unaccountable funds issued directly from the Directorate of Central Intelligence (DCI). The model began in the early 1950s with the GENETRIX program, which used experimental high-altitude reconnaissance cameras mounted in stratospheric balloons. Then came project AQUATONE, better known as the U-2, the first in a series of high-performance, high-altitude reconnaissance planes built in the middle 1950s. The imagery associated with these sensor platforms was ordered under some of the most restricted security protocols ever devised—a set of protocols originally called TALENT. Reconnaissance then went into orbit with a series of satellite-borne imagery systems, starting in 1958 with CORONA, the foundational global remote sensing system (Ruffner 1995; McDonald 1997; Peebles 1997; Day et al. 1998; Cloud 2001b; 2001c) and continuing to the present. Space-borne reconnaissance was ordered under a new set of KEYHOLE protocols. Later these were combined into the Talent-Keyhole security protocol system covering all overhead reconnaissance, which survives to the present day.

Interlude: Waldo Tobler, Frederick J. Doyle, and Amrom Katz

These three scholars and practitioners of American cartography pursued careers that exemplify the complex mixtures of academic research, public and clandestine government service, and private corporate employment. Although the exigencies of the Cold War introduced many unexpected changes to the careers of all three men, their early theoretical writings in the 1950s anticipated the important directions that American cartography would take over the next decades.

Waldo Tobler pioneered in formalizing the use of cartographic methods in analytical geographic investigations (Tobler 1976; 2000, p. 189). He anticipated the impact of computerized data processing on cartography, as well as the place of maps within complex data processing systems, by advocating methods for the formal decomposition of the map—which is not at all the same as a map's deconstruction (Sherman and Tobler 1957). Although his career has been mainly academic, his early work on radar displays for the SAGE command-and-control system at the Systems Development Corporation, an offshoot of the RAND Corporation, contributed significantly to his theoretical writings on computer automation and cartography (Tobler 1959; Clarke and Cloud 2000).

Frederick J. Doyle's career personifies the evolution of American photogrammetry from World War II through the end of the Cold War by encompassing academic positions and research projects, civilian extra-terrestrial mapping of the solar system, and some of the most secret intelligence programs in American history. In his important 1953 paper on "futuramic photogrammetry," Doyle contrasted two diverging information systems. *The qualitative road*, which was and is the predilection of intelligence reconnaissance, sought to optimize long-focal-length cameras that yielded subjective information, with dimensional information obtained through single-picture photogrammetry and approximate instrumental solutions. *The quantitative road*, by contrast, prioritized wide-angle cameras and precise photogrammetric instruments that were essentially analog computers with digital readouts connected to the photo and camera model coordinate systems (Doyle 1953, p. 739). American geographers have memorialized a "quantitative revolution" in research and applications, almost exclusively confined to academic geographers flowering in the 1960s (Billinge et al. 1984). That flowering occurred when it did because the geo-spatial convergence of the Military-Industrial-Academic-Complex had already spent over a decade following the quantitative road.

Amrom Katz's career brackets those of Tobler and Doyle. He began with fundamental contributions to photogrammetric analytical solutions (Katz 1948; 1950) and to panoramic camera design—he and Merton Davies of RAND Corporation created the original Corona scanning panoramic camera model (Davies and Harris 1988). Evolving towards systems analysis of reconnaissance and programs, his work culminated in what can best be described as complex critiques of remote sensing systems and their political context (Katz 1976; Cloud 2001a). Katz pioneered photogrammetric applications to nuclear weapons testing; by the end of his career, as Assistant Director of the U.S. Arms Control and Disarmament Agency, he was attempting to make nuclear testing obsolete.

Although these three pioneers anticipated the future presciently, the actual paths taken by American cartography were both circuitous and clandestine.

The Great Divide between Data Acquisition and Reduction

A few years preceding the original CIA reconnaissance programs, a major change in the U.S. armed forces occurred, one with consequences that would eventually re-order American cartography. In 1947, the U.S. Army Air Force separated from the U.S. Army and was reconstituted as a separate military service, the new U.S. Air Force. Over time, an often problematic division of labor and activities was made between the services, beginning with a document issued in April 1948 by James Forrestal, the first Secretary of Defense (Forrestal 1948). The most important division relative to cartographic history was that the entire process from imagery acquisition to map creation and production was divided between the U.S. Air Force, which was assigned the primary task of *data acquisition* systems, and the U.S. Army, which was to concentrate primarily on *data reduction* systems (Pennington 1973; Livingston 1992). There were important consequences to this division of labor, and, more importantly, to the research and development enterprises of the different services. For one, the Air Force's concentration on data acquisition systems soon brought it into direct competition with the CIA for the design and control of classified reconnaissance sensors and platforms. The bitter conflict that resulted endured for several decades and was only partially resolved with the creation of the National Reconnaissance Office (NRO) as a hybrid organization shared by both agencies (Hall 1998). More importantly, and in the long run more productively for the history of twentieth-century cartography, the differentiation between data acquisition and data reduction systems was paralleled and amplified by an increasing differentiation between classified programs and systems and their unclassified counterparts that developed in government and academia as unique components of the American system of Cold War knowledge production. These divisions created tensions and technological challenges, which were eventually resolved by invention of a complex ethnography of scientific and technological exchanges that triggered a cascade of novel geographic technologies, including geographic information systems (GIS) and the Global Positioning System (GPS), which have transformed modern American geography and cartography.

During the Cold War the major geodesy and mapping facilities of the Army were in Bethesda, Maryland, and Fort Belvoir, Virginia. The principal organizations included the Army Map Service, the Office of the Chief of Engineers, and the

Topographic Engineering Center.[2] A major Army Photogrammetric Engineering laboratory was at Wright Field, in Dayton, Ohio. With the separation of the Air Force from the Army, the Army retained its Ohio laboratory and renamed the U.S. Army Engineer Topographic Laboratories (USAETL) at Wright-Patterson Air Force Base, which was reconfigured as a research and liaison facility to the Air Force (Livingston 1992). The Army and Air Force interacted with the U.S. Geological Survey, particularly the National Mapping Division, and the Army and Air Force in turn related in various ways to the nautical charting and coastal geodesy enterprises of the U.S. Coast and Geodetic Survey and the Navy, which were engaged in strategic oceanographic mapping (Bossler, personal communication 1999).[3]

As the separation between the Air Force and the Army evolved, the distinctions between *data acquisition* and *data reduction* led to structural tension between the two enterprises. In essence, Army responsibilities for data reduction were best aided by photogrammetric mapping systems that privileged *dimensional stability* in a variety of ways, using optimally calibrated mapping cameras equipped to deal effectively with image motion compensation, discrete simultaneous exposures of near-vertical photography with consistent and adequate stereo-overlap, and relatively thick film stock exposed at optimum light levels for the film emulsion speed. Departure from optimum conditions by any component of the complex reduces the dimensional stability of the photography, which makes data reduction for mapping applications more difficult (Figure 1).

Because the Air Force was responsible for data acquisition, the geo-political exigencies of the Cold War inevitably shifted Air Force priorities away from systems that optimized dimensional stability to other, more classified priorities. Four suites of applications were most important: (1) *high feature resolution*; (2) *broad area coverage*, especially angled non-vertical photography; (3) *novel and untraditional sensors*, including flash-illuminated nighttime photography and radar imagery; and finally (4) *near-real-time data*, generated largely for use under battlefield conditions.

The combination of the new sensor systems and their applications, especially over hostile territory, induced another major structural distinction between the operational roles of the Air Force and Army in data acquisition and reduction. The data collection systems included some of the most important and closely guarded national secrets, while the data reduction and mapping systems remained largely unclassified. The combinations of secret data and unclassified data management systems created tensions, required subterfuge, and ultimately triggered important and unintended consequences that changed the course of American cartography.

Panoramic Progress

Scanning panoramic cameras from Katz and Davies at RAND Corporation, later extended and developed by personnel at Leghorn's Itek Corporation, became the workhorses of data reduction (Davies and Harris 1988). The cameras exposed film along a narrow slit that moved relative to the film motion, affording extensive area coverage to the sides (orthogonal to the sensor's platform's line of flight) with extremely high feature resolution. However sharp, the photography was extremely difficult to register to a map base. As panoramic cameras were adapted to the fleet of "black" sensor platforms—from balloons to secret planes to the Corona satellites—the tension between data acquisition systems and data reduction systems increased. It required the invention of what were to become the fundamental geographic technologies of the late twentieth century to resolve the tension.

Panoramic photography was addressed theoretically and through technology development. General analytical solutions to photogrammetric registration, particularly techniques amenable to the use of electronic computers, were explored (Doyle 1953). One of the leaders in this research was Helmut Schmid, a geodesist and photogrammetrist, who had been a part of Wernher von Braun's V-2 staff at Peenemunde (Schmid 1959). The projective equations of analytical photogrammetry were modified to accommodate panoramic photographs and related computational changes that expedited computer-assisted rectification (Skiff 1967). A series of optical-mechanical rectifiers were developed expressly to transform panoramic photographs, beginning with Sam Levine's early 1960s "slit-o-sizer" and extending through the versatile Fairchild Electro-Optical Rectifer, which proved critical to mapping

[2] This organization, the successor to the nineteenth-century Army Corps of Topographic Engineers, changed names and to some extent, missions repeatedly during the Cold War—i.e., it became the Geodesy, Intelligence, and Mapping Research and Development Agency (GIMRADA), then later the Topographic Command (TOPOCOM), etc. For clarity concerning the references, the enterprise will be named as it was designated at the time of the reference. However, the enterprise itself remained intact throughout this period and continues today.

[3] As the focus of this essay is exclusively terrestrial cartography, the maritime component of the story will not be examined here.

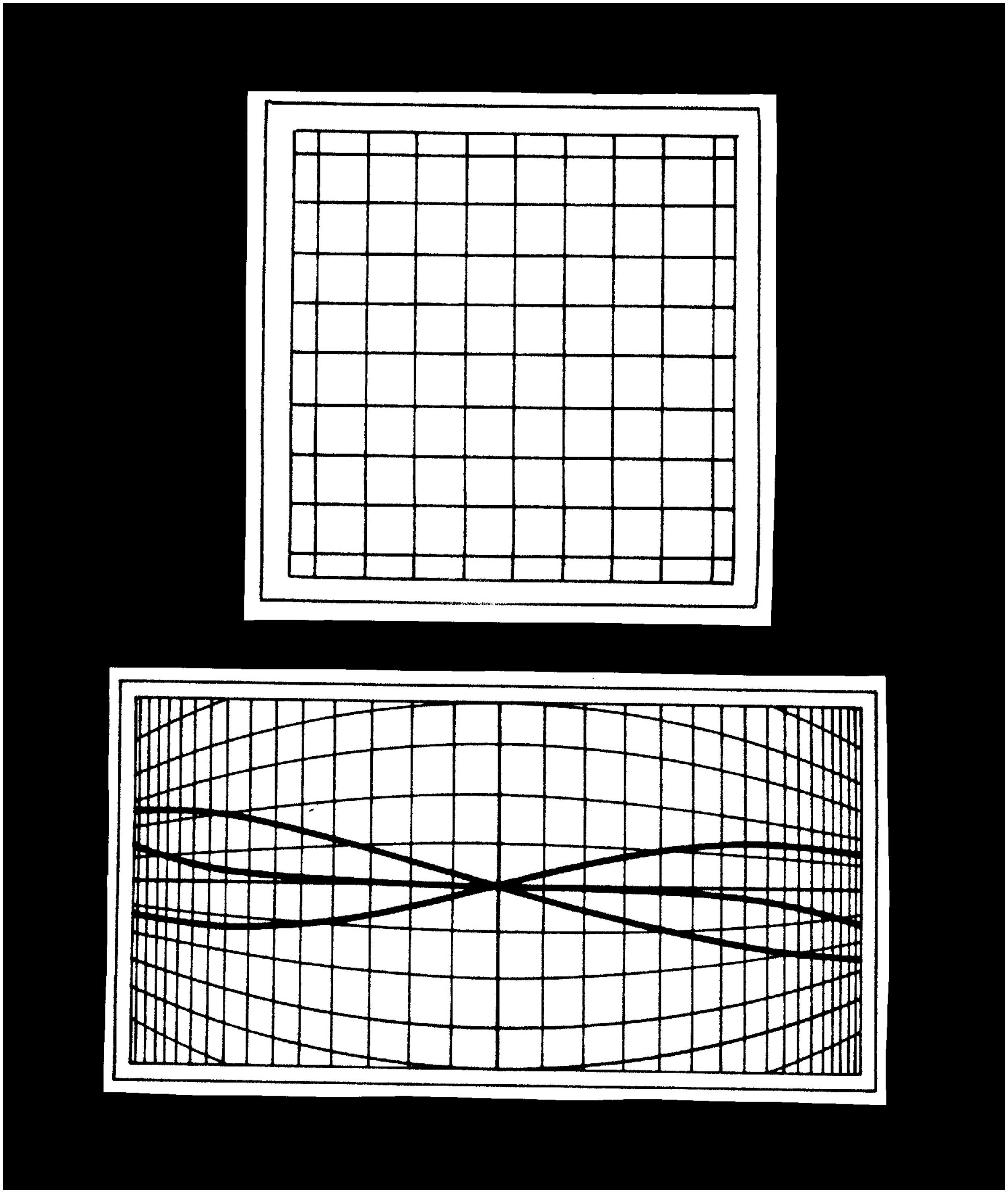

Figure 1. Dimensional Stability meets Panoramic Progress. The upper illustration represents a film frame from a well-calibrated aerial camera used for a vertical exposure over an earth covered with a grid of uniform-area squares, a data acquisition system privileging dimensional stability. The bottom illustration represents a film frame from a scanning panoramic camera flown over the same earthly grid, with three super-imposed distortions. The first results from the geometry of the focal plane and sweeping action of the lens; the second reflects the time interval of angular sweep movement while the aircraft is moving; and the third, opposite and symmetrical to the second, represents the distortion of image motion compensation introduced by the camera mechanism to correct for the second distortion. From Orlando (1967, Fig. 6 and Fig. 8, on 97 and 98, respectively).

applications on the Moon and inner planets as well as the Earth (Levine 1961; Traschsel 1967). And finally, systems were developed to pair high-resolution panoramic cameras with lower-resolution calibrated mapping cameras on the same platform, with the cameras working simultaneously. Integrating the two images was a major research challenge. As Army cartographic historian Robert Livingston noted:

> An era of complex and high priced data reduction development ensued, both in the Air Force and the Army, to accommodate use of the lower-fidelity [i.e., panoramic camera] imagery. The chief accommodation for its use was to super-impose the high-resolution pan imagery over a control network provided by the high-fidelity [i.e., mapping camera] imagery prior to delineation. The resultant 'infighting' between services zoomed into orbital levels. (1992, p. 13).

The sly reference to "orbital levels" in Livingston's history of the USAETL Field Office reflects the fact that, when it was published in 1992, the entire Corona reconnaissance satellite program (1958-72) was still classified top-secret, although it had ended two decades previously! Livingston's account reflects a broad pattern of knowledge production and concealment: while U.S. classified reconnaissance acquisition systems and their platforms remained classified, the data reduction systems that were their technological partners became more publicly acknowledged and described. Issues of *Photogrammetric Engineering* and *Military Engineer* from the era are filled with articles candidly describing new developments in rectification and mapping equipment—but remain quite coy about the specific and secret sensor systems that provide the data. The important reference handbook *Cartographic Production Equipment* presents virtually every significant technology for cartographic data reduction in use by the U.S. military at the time—and none of the data acquisition systems that had been developed to work with the data reduction systems (Data Corporation 1968).

The systems analyst and mathematician H.F. Dodge (1964) published an important concept paper on automatic mapping systems, and was candid about why they were necessary. "The potential of multi-sensor data in relation to increasingly urgent requirements for military real-time mapping or charting (mapping as fast as photography is required) provides the impetus for a very high level of research in these areas" (Dodge 1964, p. 239). He presented two schematic diagrams, contrasting the typical mapping system to a new automatic mapping system. "Acquisition photography" is prominent in the first diagram and is shown being injected into the mapping process repeatedly. But in the automatic mapping system "acquisition photography" has become a small, insignificantly sized box in the diagram—yet neither mapping system will produce maps unless the photography is acquired.

At times, in other publications, even camera systems are described in some detail—so long as the secret platforms they fly or orbit on were never stated. In 1961 and 1962, when Corona's cameras were triggering a sea change in American scientific intelligence, the Itek Corporation published two articles on the generalized panoramic cameras the firm had designed and the keys to their data reduction, under a title that characterized the era—"Panoramic Progress." There was, of course, not a single reference to the classified vehicles that carried the cameras (Itek Laboratories 1961; 1962).

Air Force cameras and their platforms, as well as the Army data reduction and mapping systems that relied on them, were at the heart of larger assemblages of military and intelligence programs. These technologies converged on cartography for a myriad of purposes, from unclassified military area mapping to clandestine special operations utilizing unique terrain models and maps produced specifically for the operation. Personnel from many branches of the Military-Industrial-Academic Complex combined and shuffled in complex patterns that spurred cartographic and geodetic innovations. Simplifying for clarity, I argue that the key, organizing concept for this cartographic convergence is well represented by a major advanced mapping system project, called RACOMS, the Rapid Combat Operations Mapping System which was in active development from 1961 to 1969. The basic requirement for RACOMS was the development of a system that could produce four 1:50,000 topographic quadrangles, of military mapping intermediate-accuracy class, from initial new photography to map production, within 48 hours (Livingston 1992, p. 156). Such a rapid turnaround could only be achieved with a geodetically correct map base system.

For combat mapping purposes, recent images photogrammetrically adjusted to the map base would provide the RACOMS maps, but the panoramic film of Corona could not be used for up-to-date photography because Corona depended upon a film-return canister jettisoned from space once a month, on average. Even so, appropriately rectified Corona imagery could be used for the map base. The up-to-date photography required aerial reconnaissance craft flown short distances over the battlefields to acquire film or data from any of the newer, more rectification-intensive sensors being developed, in particular, oblique photography, radars, and infrared line scanners. The novel sensors were distinct, but all were similar in that the novel systems privileged something other than dimensional stability, which was paramount to traditional photogrammetric mapping systems. Nevertheless, the challenge to the U.S. Army remained the difficult task of integrating the data into the larger cartographic data system.

The RACOMS decade of the 1960s was a productive period for all aspects of data acquisition and reduction systems, across all platforms, secret or not. But productivity came at a high price, both in terms of capital and the difficulties imposed by security restrictions. It is probably impossible to estimate accurately the funds spent on the full cartographic enterprise. The "black" budgets for Corona and its allied secret sensors will never be disclosed. Even so, one can assume that the classified mapping applications based on top-secret sensor systems were probably even more expensive than the publicly acknowledged mapping systems for which budget figures are known.

The Air Force and Army collaborated from 1960 to 1970 on a sophisticated aerial mapping system, designated RC-135A/USQ-28 (Robson 1963). A central, on-board computer system was to integrate inertial guidance systems with instantaneous georeferencing through reception of ground SHIRAN (*S*-Band *Hi*gh-Precision Short-*Ra*nge *N*avigation) transponders, a gyroscopically stabilized mapping camera, and an array of other sensors and data recorders. The RC-135A/USQ-28 mapping system, which functioned from 1969 to 1972, may be considered, in part, a major component of the realized technologies developed to fulfill the RACOMS requirements. The total development costs for the RC-135A/USQ-28 system in dollars of the day exceeded $120,000,000 (Livingston 1992, p. 86). The project was cancelled because U.S. Air Force and Army development interests were shifting to the still classified satellite systems that followed Corona. Army historian Robert Livingston, writing prior to the acknowledgment of the National Reconnaissance Program, used euphemisms to note that the aircraft-based RC-135A/USQ-28 system was replaced by a new enterprise directed in the 1970s to "what was termed 'global mapping' at that time"—an indirect reference to top-secret satellites in polar orbit (1992, p. 36). The total development costs for these secret systems, added to the known costs of the RC-135A/USQ-28 system, suggest that the total costs of "panoramic progress" probably exceeded a third of a billion dollars of the day—if not more.

The scale of these mapping objectives, their associated budgets, and the creative tension between disparate and competitive enterprises engendered dozens of new corporations and "think tanks," such as Itek and Autometrics, Inc., the principal mapping systems integrator for the Corona camera systems (Doyle 1998). As personnel rotated in and out of government service and private and university work, they were enrolled in what a top-secret CIA memorandum termed "the codeword mapping community" (National Reconnaissance Office 1966, p. 14). That community would take developments in remote sensing and its applications in directions unanticipated only a few years earlier in the Cold War.

The Earth through a Keyhole

With the cascade of technical advancements in mapping systems during the 1960s, disparities increased between the secret systems and their publicly accessible and unclassified counterparts. In response, a series of perhaps counterintuitive initiatives developed. Originating in the secret (codeword) mapping community, they were designed to disseminate the results of their technical achievements without compromising the sources and methods by which those results had been achieved. American classified technologies during the Cold War were often referred to as "black boxes." In the case of reconnaissance and mapping applications, however, the box in question was quietly retro-fitted with shutters, which revealed discretely the most important geographic technologies of the era (Clarke and Cloud 2000; Cloud 2001a).

In the mid-1960s, for example, while NASA and the Geological Survey were exploring possibilities for the civilian earth-sensor satellite system eventually realized as Landsat, the mysterious ARGO Committee, which is still classified, requested the staff of Autometrics, Inc. to create a unique application of reconnaissance photography. Clinton Peppard of Autometrics was directed to rectify and enlarge Corona-Argon mapping camera photography of Africa, acquired from 1962 to 1964, to assemble a giant photomosaic of the continent in a Lambert conformal conic projection (Peppard 1998). This photomosaic (Figure 2), the first relatively high-resolution image of the continent, was assembled on the floor of a classified warehouse

Figure 2. The Great Africa Photomosaic. The illustration is a pocket-sized, very-small-scale version of the much larger original African photomosaic prepared in the middle 1960s by Clinton Peppard of Autometric, Inc., at the direction of the still classified ARGO Committee. Fingerprint traces on the image convey its reduced size. The photomosaic was assembled from Corona-Argon mapping camera photography acquired 1961-1964, rectified to a Lambert conformal conic projection controlled by re-scaled World Aeronautical Chart (WAC) maps. Subsequently photomosaics of Antarctica and the Arctic Ocean Basin were also produced. [The image is courtesy of Clinton Peppard, and Autometric, Inc., and also the National Reconnaissance Office.]

in Maryland. Several dozen civilian earth scientists were given Talent-Keyhole clearances so that they could enter the warehouse, examine the huge image, and better appreciate what one could do in the earth sciences from space. Autometrics later assembled similar giant rectified photomosaics for Antarctica and the Arctic Ocean Basin (Doyle 1998). These exercises, and many similar projects, were the clandestine roots of the later unclassified and supremely visible Earth Resources Technology Satellite (ERTS), better known as Landsat.

The development pattern of classified programs filtered into unclassified applications extended beyond the Earth to the rest of the solar system. The immediate successor reconnaissance satellite system to Corona was SAMOS, which differed from Corona in that its film was developed in space and scanned by a flying spot line scanner that converted the imagery into an electronic signal and transmitted back to Earth, where it was assembled into a composite image. Declassification of the system in 2001 revealed that a slightly modified version of top-secret SAMOS was dispatched in 1966-67 on five successful flights to the Moon—as the completely unclassified NASA Apollo Lunar Orbiter mapping camera (Hall 2001)! Similar concealed technology transfers aided the Mariner and Voyager programs and their mapping missions to Mercury, Venus, and Mars.

The disparity between civilian and classified mapping capabilities eventually induced efforts to consolidate the entire array of federal cartographic and geodetic enterprises. In 1973, the Office of Management and Budget (OMB) Federal Mapping Task Force released a report advocating sweeping changes in the federal cartographic infrastructure. In their conclusion, they noted:

> The lack of civilian MC&G [mapping, charting and geodesy] involvement has been accompanied by *the development of expensive systems for civilian use that cannot compete in any meaningful way with DOD-developed techniques*. Failing to adapt to new technology will mean continued pressure for redundant and less-efficient systems… We believe that federal civilian MC&G resources can be made more productive by a community reorganization based on establishing a comprehensive and integrated program to provide multipurpose products (OMB 1973, 7-11, emphasis added).

The task force's recommendations were partially implemented. Nominally civilian federal agencies were integrated into the classified infrastructure by quietly acquiring their own classified labs, so that they could use intelligence and classified materials. The first building at the new USGS National Mapping Division complex at Reston, Virginia, was Building E-1—a Talent-Keyhole-level, secure, compartmentalized intelligence facility (SCIF). Inside Building E-1, USGS civilian personnel had access to U-2 and SR-71 aerial reconnaissance photography as well as Corona film from space. The Geological Survey has been mapping the nation with top-secret intelligence assets for a third of a century, although none of this was ever publicly acknowledged until the declassification of Corona (Mullen, personal communicaton 1998; Starr 1998). Nevertheless, USGS maps have hinted at these developments. Starting in the late 1960s, the photo-revised USGS 7.5-minute quadrangles have noted, in their legends, that the photo-revisions are based on "aerial photography and *other source data*" (emphasis added). The "other source data" were and remain the deepest secrets of the nation.

Discreet collaborative uses of intelligence data persist, and they are formalized in the activities of the Civil Applications Committee (CAC). As the broker between the intelligence community and the rest of the federal government, this federal inter-agency committee coordinates the uses of classified assets of all types for a wide array of applications in order to support mission-critical activities of the relevant agencies (Anderson 2001). Directed from the USGS National Mapping Program offices, the CAC is the direct legacy of the pioneering applications of Corona and other classified reconnaissance systems to civilian cartography.

An earlier report of the OMB Federal Mapping Task Force had recommended that all federal military and intelligence mapping, charting, and geodesy enterprises should be consolidated into one agency. The creation of the Defense Mapping Agency (DMA) partly accomplished this goal. This consolidation reinforced and enlarged certain cartographic enterprises, and eliminated or truncated many others. As it happened, there were dramatic budget cuts and consolidations of U.S. Army cartographic intelligence research efforts, at the Topographic Engineering Center in particular. This had a dramatic impact on the evolution of one of the Army's most important classified development projects, but also the subsequent histories of the project's origins.

Layered Truths: The Origin of Geographic Information Systems

The primary task for military geographic information (MGI) is terrain analysis, at all relevant scales, for whatever military objectives have been determined. During the Cold War, the combination of radically changed global geo-politics and an array of new weapons systems made novel and complex demands on the system designers who created Cold War MGI systems. In this final section, I examine the incomplete development of what was to be the

Army's and the Air Force's final major cooperative research and development project, immediately before 1972, when the separate service-level complexes were reformed into the Defense Mapping Agency, later renamed the National Imagery and Mapping Agency (NIMA).

Just as geo-political advantage favored photogrammetric systems featuring novel sensors, priorities for new weapons systems favored major research on ways to define terrain and its characteristics in digital form. As Wernher von Braun's V-2 terror-weapon rocket became both the ICBM and the moon rocket, so too did the German V-1 buzz-bomb jet become the first U.S. cruise missile. Cruise missiles are, in essence, pilotless aircraft, so from the beginning of American development of cruise missiles a major component of the research has been pilotless geo-referencing and navigation systems merged with terrain analysis. The first American terrain sensing guidance system was ATRAN (*A*utomatic *T*errain *R*ecognition *a*nd *N*avigation), initiated in 1947 by Goodyear Aerospace Corporation under contract to what was then the Wright Air Development Center. The ATRAN system used forward-looking radar imagery continuously compared to a sequence of reference images stored in its memory on 35mm film. The reference images were photographed by Army Map Service from oblique views over 1: 250,000 scale, highly-exaggerated, vertical relief three-dimensional map models. The system was in full operational production by 1955, being in demand as the guidance system for the MACE missile, which was in use through the mid 1960s (Koch and Evans 1980).

In the next iteration of missile evolution, inertial guidance systems coupled to digital computers were developed for ICBM rockets (MacKenzie 1990). Inertial guidance systems were then adapted to cruise missiles, but the cruise missiles retained a terrain-observing function, not as the primary guidance system, but rather as a source of data that could be used to update the inertial guidance system. The basic concept of the system designed for the new missiles was TERCOM (*Ter*rain *Co*ntour *M*atching). This system operates on the premise that any single geographic location on the Earth's surface is uniquely defined by the vertical contours of the surrounding terrain. Contour data obtained during the missile's flight are compared to reference contour data in the guidance system computer to update and correct the missile's inertial system. TERCOM began in 1958 as the guidance system concept "Fingerprint," proposed by Chance-Vought for SLAM—a nuclear-powered, supersonic, low-altitude missile (Golden 1980)! The Aeronautical Systems Division of Wright-Patterson Air Force Base funded initial development of the concept, followed by subsequent development and research by enterprises and people spanning the entire MIAC. In some form or other, TERCOM is resident in every American missile and many American aerial bombs in use today.

As ATRAN became TERCOM, physical three-dimensional terrain models became digital terrain models. And as in so many other aspects of this story of Cold War cartography, fundamental progress in digital computing was synonymous with developments of cartographic-related applications. In the case of digital terrain models, though, many parts of the history still remain unclear. Much of the primary development work was done by staff at the MIT Photogrammetric Laboratory, under contract to the Army/Air Force nexus (Miller and LaFlamme 1958). Much later development work on a particular type of cruise missile terrain model, the TIN (*T*riangulated *I*rregular *N*etwork), was performed by unclassified researchers, who were told that the intended navigational function was to find lost civilian airline pilots and automatically return them home (Mark, personal communication 2001).

TERCOM terrain modeling for cruise missiles is a specialized case of MGI terrain analysis. Because it is concerned with maintaining orientation at a distance above the actual terrain, the undulations of the surface are paramount, and all other aspects of the landscape are insignificant. For terrestrial applications of MGI, however, various properties of the landscape, such as slope, soil types, vegetation cover, and infrastructure, assumed primary importance. Initially these properties were evaluated in the tactical terms of the battlefield, but over time the battlefield would once again be resolved more generally as a landscape, and the technologies developed for that enterprise would transform the science and practice of American cartography.

By the middle 1960s, Colonel Lloyd Rall, commander of the Topographic Engineering Center (in its earlier incarnation as GIMRADA…), described the evolving research directions of the complex. Given the volumes of geographic data the center was already handling, and with even more data "coming [our] way as we move out into space," the research enterprise had decided on an MGI strategy that "recognized the tremendous efficiency of the photo image as a storage medium and the problem of data redundancy which it brings with it. Hence, we have developed a philosophy of change detection as a basic redundancy elimination scheme" (Rall 1966, p. 979). Rall here echoes Waldo Tobler's arguments from a decade earlier about maps and photographs as information storage and analysis media. The complex of equipment developed to achieve this goal included an Optical Plus Electro-Optical Change Detection Unit, which was coupled to digitized terrain data, and the Natural Image Computer, a pioneering optical computer developed for automatic image extraction and symbolization. An advanced concept for geographic imagery analysis using an optical computer, the Natural Image Computer operated on all points of detail simultaneously and in parallel. The image was geo-referenced at the pixel level, to aid geographic calculations, while the image retained the shared contextual logic of the entire scene. As with other Cold War technology systems, panoramic progress was all but synonymous with computational progress in the sense that the project could only accomplish what it could program (Rall 1966, p. 982). These technologies, combined with the data flows from the undescribed (and top-secret) sensor systems they paralleled, would create a system of geographic data systems. As Rall noted:

> We expect, eventually, that change detection, automatic image extraction, and automatic mapping will interface into a multi-capable system of high versatility. The capacity of such a system to produce annotations, revisions, orthophotomaps and standard maps should be at least an order of magnitude above that of which we are now capable… . This forms a formidable data base which, for size and complexity, probably has no equal. We are studying the structure of such a data base and how it may be encoded for computer input and manipulation. Currently we have work in progress, in house and on contract, to study discrete portions of such a data base, and encode them and manipulate them in a specific experimental military computer system for command and control (1966, pp. 984-85).

By 1968 the guiding concept for this experimental military computer system had been given the name Military Geographic Intelligence Systems (MGIS) (Pennington, 1973, p. 290).

As the cascade of geographic data issued from new sensor systems and elaborate new data reduction systems, the directors of MGI research began to consider data management systems based on data that were increasingly organized and systematically abstracted from the signatures of the environment. This movement is especially pronounced in the movement away from traditional MGI mapping based on *trafficability*, which involved assessment of the relative ease of motion for specific types of military vehicles and operations. An example of trafficability mapping would be a map that portrayed areas where tanks of a certain type could or could not drive, based on an assessment of the specific landscape in terms of critical factor values (such as maximally allowable slopes) germane to that class of tank. As MGI data systems became more sophisticated, their designers and users moved steadily away from linking the analysis to specific military applications, or even military applications in general. As J.R. van Lopik, a theoretician of military geography, noted in 1962:

> It is extremely important, however, that future descriptions of terrain in areas where performance or success of mission is evaluated be quantitative in nature. This is true because qualitative and subjective descriptions of terrain do not provide cause-effect data that can be objectively applied or transferred to other regions. In summary, terrain studies for military purposed require precise, quantitative and objective methods for describing, classifying, mapping and comparing terrain in terms that are *naturalistic and not necessarily related to critical value factors* (van Lopik 1962, p. 775, emphasis added).

In effect, practitioners of MGIS were uncoupling quantitative methods from critical factors for trafficability, and in doing so were themselves removing the "M" from within, to reveal GIS.

There were also centripetal forces brought to bear on MGIS, with the steep increase in applications of American military geography that occurred in the second half of the 1960s and the early 1970s. The research enterprise of the Army/Air Force nexus was principally directed to development of new instruments and techniques to describe, classify, map, and compare terrain. As more and more that terrain was situated in South East Asia, MGIS went to war.

I propose that the "M" in MGIS was lost in the great reduction and simplification of MGI research as the research nexus was increasingly directed to the mapping of first theoretical and then actual battlefields. In 1963, the Army Map Service received an assignment from GIMRADA to produce an accurate marking instrument for transferring and matching image points on "photographs with large changes in format size and scale." The machine that the Army Map Service invented, the Variscale Stereo Point Marking Instrument, was "the first marking instrument to provide a point-transferring capability for analytical aerial triangulation for both equal- and unequal-scale photographs" (Roos 1967, p. 1260). The "unequal-scale photographs," never further specified, were principally panoramic photographs, and the new machine was another incremental advance in panoramic progress. An even higher-level technology developed for rectification of reconnaissance photography to either established map bases or geodetically rectified photography was the Target Map Coordinate Locator, which was combined with the Natural Image Computer and a small new sophisticated printing system, the Multicolor Electrostatic Printing Machine, to form a complex that GIMRADA commander Colonel Lloyd Rall had described as the GIMRADA Micro-Map System, essentially a production implementation of the theoretical RACOMS combat mapping system goal (Rall 1966, pp. 985-986). As always, the secret data acquisition systems integral to the system remain undisclosed and not discussed, but the data reduction and mapping applications technologies were displayed and carefully described on the pages of the Defense Intelligence Agency's *Cartographic Production Equipment Handbook* (Data Corporation 1968).

Panoramic progress was used increasingly to determine targets. The scale of the mapping and charting enterprise set up to create, correct, update, publish, and distribute maps and digital data for the enveloping conflicts in South East Asia was unparalleled. Its closest analog was the American cartographic mobilization for World War II, but major differences between the earlier and later wars were telling. The first difference reflected recent advances in cartographic technologies. During World War II, the best hope for an accurate national-scale map base for enemy-occupied territory was to capture enemy maps and geodetic data. For Vietnam, a geodetically correct cartographic map base for all of South East Asia was created from scratch, even though the French colonial geodetic network data were available (Morrison, personal communication 2002). The long-sought goal of a RACOMS combat mapping system was first implemented in Army experimental labs in the GIMRADA Micro-Map System, then projected onto the battlefield in the form of the Tactical Image Interpretation Facility (TIIF). The TIIF was "a self-contained equipment mounted in an expansible van for extracting intelligence information from photographic, radar, and infrared imagery… [T]he imagery (paper positives and transparencies) may originate from Army, Navy, Air Force, and *other agencies*" (Orlando 1967, pp. 92-93, emphasis added). A variety of miniaturized rectification and image management equipment was coordinated through the Field Data Digital Army Computer (FIDAC), which could automatically calculate distances and positions as well as "determine map coordinates of targets under observation" using radar imagery and oblique, panoramic, and infrared photography. The increasing ease and accuracy in targeting, in turn, became the foundation upon which the Vietnam and post-Vietnam American battlefield command-and-control system was based (Doleman 1985).

For military planning beyond the tactical battlefield scale, and especially for targeting artillery and aerial bombing missions, the Army/Air Force nexus developed the Point Position Data Base (PPDB), in which Corona came full circle. Less than a decade earlier, the main cartographic task was to rectify high-resolution Corona panoramic film to the dimensionally stable mapping camera film. Computational rectification had now advanced to the point that geodetically rectified panoramic Corona photography was used as the dimensionally stable map base itself, with near-real-time photography and imagery from locally based reconnaissance planes then rectified to the geodetically rectified Corona photography (Ayers 1998). This represented the earliest stage of the return of the privileging of *dimensional stability*—except now the term referred to the base of geo-rectified pixels, instead of the original stable film base.

As the scope of U.S. warfare in South East Asia increased, so too did the kinds of maps produced, and their uses. A key system integral to the political concepts underlying American engagement was the Hamlet Evaluation System, which was predicated on theories developed by American sociologists and political scientists. They proposed that the political stability of individual Vietnamese hamlets could be rated and evaluated based on multivariate interview data gathered from village members (Huntington 1969). Though the theory proved to be erroneous, the Hamlet Evaluation System became ubiquitous. Colonel Erwin Brigham, Chief of the Research and Analysis Division, Civil Operations for Revolutionary Development Support (CORDS) at the Military Assistance Command headquarters in Saigon noted that,

> . . . one of the most interesting developments is the use of the Province Hamlet Plot (1: 250,000), an overlay showing location and category of each hamlet, by province, in Vietnam. U.S. and Republic of Korea units use the plots in planning tactical operations; U.S. artillery units use them in planning their operations.

> The GVN [Government of Vietnam] National Police use these data in their campaign against the VC [Viet Cong] infrastructure and the U.S. Air Force Office of Special Investigations in Vietnam [is] using the HES Information report to assess population and area control in their work (Brigham 1968, p.12).

The cartographic workload became so large that portions of the work were outsourced to the USGS National Mapping Division. This period preceded the "official" enrollment of USGS in classified mapping programs, which began with the construction of the top-secret SCIF Building E-1. As a security workaround, USGS cartographic personnel were given classified Corona panoramic photography but were not told its source or that it was classified. Roy Mullen, the USGS director of special projects at that time, noted the growing horror both portrayed and concealed by the enterprise:

> USGS was commissioned by the State Department to prepare civilian land reallocation maps for South Vietnam, and we were commissioned by Army Map Service to prepare battle maps of North Vietnam. They were the same maps. *They were the same maps!* (Mullen, personal communication 1998, emphasis as in interview).

And so it was that the power relations that reside in all cartography engulfed this supremely productive Army/Air Force/Intelligence Community nexus as well. Cartographic historian Brian Harley (2001) drew attention to both intentional and unintentional silences, which determined what *doesn't* show on maps, and why. Besides Harley's original silences, which are features that do not appear on the map, the history of American cartographic transformation in the Cold War reveals two other kinds of cartographic silences. The first is that presented by cartography based on secret resources for which the secret remains concealed. This is the purloining of the map, by hiding the secrets in plain view, as most contemporary American government maps do, since they are all based, to one degree or another, on classified assets. The second new type of silence is represented by battle maps that were also civilian land reallocation maps, and vice versa. The geodetic accuracy, the spatial relationships, the geographic "truth" between hamlets was identical, but the maps validated different political concepts, and the ways they were used to literally "target" the populations were quite distinct. Another, more insidious type of silence was created by the success of the targeting. As the world watched in mounting horror, the American enterprise infamously "had to destroy the village in order to save it," which reflects, precisely, the contradictions inherent in the two different types of maps *that were the same*. It is estimated that three million Vietnamese died during the American engagement in their country; their absence is perhaps the greatest and darkest of the silences of the maps of the war.

As it was, the great Army/Air Force cartographic nexus was soon changed profoundly, enwrapped in an organizational silence of its own. There had always been the distinction between classified data-acquisition sensors coupled to relatively unclassified data-reduction equipment. The combination of the two was obviously the objective, and by the end of the 1960s the intelligence "bundle" represented by the complex was pulled up into increasingly classified status, particularly as the mapping complexes "went orbital" with advanced Corona, overlapped with the next two-or-three-generation satellites and very high altitude reconnaissance plane imagery systems. The cartographic researchers and system designers of the Topographic Engineering Center were at the center of these changes. At the time that the MGIS advanced development project was approved, John Pennington, the Topographic Engineering historian, noted that "the staff of the [TEC] intelligence division [material excised] was involved in a number of other programs, *both within and outside DOD*, all of which were related to and supported the overall MGI effort" (1973, p. 290, emphasis added). At about the same time, Donald Light, in charge of the implementation of systems concepts at TOPOCOM, noted that mapping programs from the Moon and back to the Earth were being transformed by the integrated development programs that converted photography and other sensor imagery to pixels, specifically to geo-referenced pixels called "ortho-pixels" (Light 1971, p. 434). Light proposed that all input imagery be converted to ortho-pixels at the initial stage of data processing, so that all subsequent analysis and comparison between data layers and elements could be performed by co-registration of the ortho-pixels:

> When it becomes fully operational, identification and classification of cultural features and landforms of special military and economic significance may take on a quantum jump in efficiency due to the concept of having the pixel imagery already in the data barrel. That is, since the pixel imagery is in machine form, it can be searched and compared at electronic speed. *Military geographic information specialists* at the TOPOCOM are pursuing these problems with vigor at the present time (Light 1971, pp. 444-45, emphasis added).

These MGIS-developed ortho-pixels are the final great convergence of the entire Cold War cartographic enterprise. In the ortho-pixel can be seen to meet: the culmination of Frederick J. Doyle's goal of futuramic photogrammetry by fully computational methods; Waldo Tobler's expanded notions of maps as integral data processing systems and his concept of multiple-use map elements; and Amrom Katz's visions of successful systems integration of reconnaissance. In a sense, the ortho-pixel represents the final triumph of the Army's quest for dimensional stability insofar as the privileged stable dimensions are now those of the entire volume of geo-rectified data, "the image of the world in a data barrel" (Light 1971, p. 445). Even so, that world can now be accessed only through a keyhole—of Talent-Keyhole security protocols.

The ortho-pixels could be openly discussed because they were the end products of the Army's traditionally unclassified data reduction systems. In the next generation of reconnaissance, however, the sensors "went digital," which meant that the initial pixels themselves began as highly classified data. As a result of these other programs, and their classification levels, the major part of MGIS development necessarily also went top-secret.

A crucial divide was reached. The research enterprise of classified MGIS continued and expanded based on improved data from the next generations of classified sensors. MGIS systems with much lower capabilities, resolution, and funding levels were pushed out into civilian use—with the "M" removed—reborn as Geographic Information Systems (GIS). The initial GIS applications were part of major efforts to transfer military systems and approaches to the problems of poor, decaying American cities (Light in press). The approaches generally targeted "urban blight" as the problem, and urban renewal as the solution. Not surprisingly, given its origins, early GIS proved useful for the task of "destroying the neighborhood in order to save it."

Conclusions

The most important legacy of the great American Cold War geo-spatial convergence was, and remains, the fact that its brilliant achievements, in conjunction with those of its Soviet and Russian counterparts, have thus far spared the world the conflagration ever imminent as long as nuclear weapons exist. With success comes inevitable historical divergence, compounded by the complex interplay between secret and public institutions and programs that was and is at the heart of the enterprise. This means that in general, the postwar histories of cartography, geodesy, photogrammetry, and geographic information science do not reflect the degree of integration between disciplines that was essential to their common advance. Moreover, the extent of the military and intelligence contributions to the disciplines remains particularly little known. Clandestine geographic intelligence has been and continues to be hidden as in Edgar Allen Poe's famous story "The Purloined Letter," by being carefully concealed—in plain view.

The relationship between MGIS and GIS is particularly contentious. The fundamental challenge of MGIS was to implement appropriate geo-rectification of panoramic photography and other novel imagery in new digital database and mapping systems; the solution involved overlaying the imagery with map base imagery. The same techniques were transferred to GIS systems to allow geographic integration by *thematic overlay* (Harvey 1996), a cartographic application with clearly recognized but little researched roots in analog maps of real estate and city and regional planning efforts throughout the twentieth century (Steinitz et al. 1976), and linked to earlier pioneering nineteenth-century cartographic techniques, particularly the mapping of moral statistics (Robinson 1982). Historians of GIS, through ignorance or epistemology, have ignored the MGIS roots of GIS, positing instead a history in which the technology seemingly drops from the skies in the late 1960s (Foresman 1998). This is true only in the sense that GIS may be said to have dropped out of space with the capsules of Corona panoramic photography.

As did much else. John Pennington notes in his history of MGIS and its major theoreticians in the intelligence division of the Topographic Engineering Center that: "…the intelligence division [was] later renamed successively geographic intelligence, geographic sciences, geographic systems, and geographic sciences. . ." (1973, p. 290). Military name changes are generally accompanied by reorganization. Within the probable chaos represented by those repeated reorganizations, the great creative froth of this vast cartographic transformation is still evident. In the changing names of the intelligence division in 1969 one can read the future of American cartography for the remainder of the twentieth century and into the next.

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