CHAPTER 18

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GEOTECHNOLOGY, THE U.S. MILITARY, AND WAR

Nothing during the past fifty years has exerted so great an influence on geographic cartography as has the occurrence of two world wars. (Arthur H. Robinson, 1954)

Abstract Geotechnologies have always been an integral part of military training and war. Maps as keys to effective strategies have been and remain essential in planning and combat. They have been supplemented by aerial photography, remotely sensed images, and recent advances in GIS and GPS. This chapter focuses on the uses of major geotechniques by the U.S. Army and Air Force during major wars of the past century. Many of these innovations in military geotechnology can also be used in peacetime and nonwar arenas. The demand for geographic information and spatial analysis continues with new technologies to map, represent, and analyze spatial and environmental data.

Keywords cartography, remote sensing, satellite images, digital technologies, military geography, war, geoinformation

1. INTRODUCTION

Since prehistoric times, humans have used technology to overcome their physical limitations. Violent action, whether hunting large predators for food or engaging in warfare with neighboring tribes, spurred rapid technological advancement. The human propensity to engage in armed conflict accelerated this leveraging of technology to produce more efficient warriors and armies.

Geographic technology made significant contributions to military effectiveness, while war and preparation for war provided an impetus for the rapid development of geographic technologies. The purpose of this chapter is to detail how U.S. military activities and warfare have both affected and been affected by the evolution of geographic technology. Geographic technologies are defined as the geographic information processing techniques, which most often include cartography, remote sensing, geographic information systems (GIS), and global positioning systems (GPS). Other technological

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innovations important in subdisciplines, such as meteorology, are mentioned where appropriate.

2. PRE-WORLD WAR I

In hunting and gathering societies, knowledge of the landscape was a matter of survival. Knowing the spatial distribution and attributes of hunting grounds, water resources, and sheltered places for encampments was an absolute necessity. Knowing how to get from one place to another was equally important. Much of this information was passed down from generation to generation through oral tradition, experience, and rudimentary drawings on cave walls (Roberts 1993). Knowledge of the landscape and the location and attributes of both friendly and enemy forces has also been essential to warriors since the beginning of armed conflict. Graphic representations of terrain, hydrographic features, settlements, and friendly and enemy forces were a critical tool for commanders. Early unscaled sketches were eventually replaced by scaled graphical representations known as maps (James and Martin 1993). Cartography (the art and science of making maps) was one of the earliest contributions of geographic technology to warfare, and the science of cartography was advanced by the patronage of leaders engaged in military activities.

Maps serve multiple purposes for the warrior. As the U.S. Army map reading manual states,

> No one knows who drew, molded, laced together, or scratched out in the dirt the first map. But a study of history reveals the most pressing demands for accuracy and detail in mapping have come as the result of military needs. Today, the complexities of tactical operations and deployment of troops is such that it is essential for all soldiers to be able to read and interpret their maps in order to move quickly and effectively on the battlefield. (Department of the Army 1993, 2-21)

Soldiers use maps to understand the nature and location of the natural and human-engineered features on the landscape on which they operate. Topographic maps, originally developed to enhance artillery effectiveness, show both landforms and elevation through the use of contour lines. They enable soldiers to visualize the terrain they occupy, and perhaps more importantly, to visualize and plan operations on enemy-held terrain they intend to attack. Thus, maps can be used for terrain visualization and understanding; terrain analysis to identify cover and concealment and routes of movement, navigation, and command and control to communicate maneuver instructions to friendly forces and to target enemy ones. The map in support of these functions has evolved since the first recorded Sumerian and Babylonian mapping efforts, and it remains the premier instrument of military intelligence, decisionmaking, and command and control (O'Sullivan 1991).

Observation of the actual terrain has been nearly as important as mapping it. The original method to increase observation was to seize the high ground. As early as the 18th century, military forces experimented with sending observers aloft in tethered balloons to increase the range of their observation. This method was largely unsatisfactory, however, until the development of photography in 1826 made possible the recording of ground activity for later analysis by intelligence experts. Balloon observation was used during the American Civil War but the fluidity of the battle precluded its use with cameras, and it provided little usable information. The U.S. Army also experimented with cameras mounted on large kites; some of these were reportedly used in the Spanish-American war. In some cases, surprisingly good results were obtained, but the difficulties of sufficient wind from the needed direction made this an unwieldy technology that was soon rendered unnecessary by the Wright brothers and their airplane. Military establishments in Europe and the U.S. were quick to recognize the potential of the airplane as an observation platform. The first aerial photograph was probably taken near Le Mans, France in 1908. In the fall of 1911, the U.S. Army Signal Corp established a flight training school at College Park, Maryland and the American Army began experiments with aerial reconnaissance. The U.S. Army successfully used visual and photoreconnaissance between 1913 and 1915 in the Philippines and along the U.S.-Mexican border (Stanley 1981).

3. WORLD WAR I

World War I prompted a number of advances in cartography and especially the nascent field of photoreconnaissance, which would evolve into the modern field of remote sensing. As William Burrows (1986, 32) said, "If the camera and airplane were the mother and father of photoreconnaissance, then World War I was its midwife." The stalemate in the trenches coupled with the generals' fear of what the other side was preparing forced both sides to look for ways to see beyond the front. While the collection component of aircraft, camera, and film technology evolved rapidly, the analysis component of image interpretation also developed and proved its worth. Comparative coverage or change detection was a cornerstone of image analysis and developed early-on. Interpreters were taught to spot points of interest and to "exploit" what they saw to draw valid conclusions about enemy intentions. Stereoviewing to see the battlefield in three dimensions, target graphics, strip coverage, and photomosaics that showed large areas of the battlefield were other innovations from World War I (Stanley 1981).

While cartography had been important before World War I, the expertise of "geographic cartographers" coupled with other geographers proved essential once again. Topographic mapping provided tools for intelligence, planning, movement, logistics resupply, artillery bombardment, and command and control. Many geomorphologists and geologists were consulted concerning the effect of soils, hydrography, and the underlying bedrock, which proved to be critical knowledge in the era of trench warfare (Russell et al. 1954). Geographers were also involved with the peace conference which followed the war (James and Martin 1993; Palka 1995).

4. WORLD WAR II

The U.S. emerged from the interwar isolationist period badly unprepared for the coming Second World War. Geographers were quickly pressed into service for a multitude of tasks including mapping, area studies, photo interpretation, meteorology, and geomorphology. Many of these geographers were in Army intelligence while others were scattered throughout the War Department and other services (Palka 2002). In addition to mapping technologies, other innovations emerged that would later prove to be of enormous value, such as radar, sonar, and ballistic missiles.

World War II produced more cartographic activity than had been seen in more than a decade. As Robinson (1954, 558) notes, "Probably more maps were made and printed during the five years from 1941 to 1946 than had been produced in the aggregate up to that time." During World War II, the use of aerial photography and photogrammetry to provide base data for maps was perfected, thus contributing to a significant improvement in geodetic control and the massive increase in world topographic coverage. Wartime cartography progressed along four lines: (1) compilation of map information, and a program to publish maps, (2) map intelligence, (3) place-name intelligence, and (4) terrain modeling. For the first time in the U.S., standardization of place names became critical because the best maps of certain theaters of the war were lettered in alphabets other than Latin (Russell et al. 1954). In addition, World War II prompted great strides in mass production techniques, the development of aerial charts for aerial navigation, special purpose or interpretative (thematic) maps, and techniques for producing terrain models (relief maps) (Robinson 1954).

While many elements of aerial photography and image interpretation were developed in World War I, large strides in both areas and especially in the airphoto coverage of the world were made during World War II (Kline 1954). By 1940 the interpretation of airphotos had grown from a tool of tactical operations specialists and cartographers to a full-fledged discipline. Aerial photoreconnaissance and interpretation also took on a strategic role with the advent of long-range strategic bombing of the enemy's industrial heartland. Long-range strategic reconnaissance with the associated aerial photographs was essential for target analysis, selection, and subsequent bomb damage assessment (Stanley 1998). Technical improvements in aircraft, cameras, and film supported both the tactical and strategic efforts. The widespread use of triple lens cameras provided both vertical and two oblique photos producing horizon-to-horizon coverage. Auto-compensating long focal-length lenses of up to 240 inch (610 cm) focal lengths enabled aircraft to take crystal-clear pictures from as high as 40,000 feet (12,192 meters) thus avoiding anti-aircraft fire and enemy fighter planes. New film came into use, such as normal color film and infrared film, which proved to be very useful at finding a camouflaged enemy. Late in the war, the British Royal Air Force pioneered the use of "radar reconnaissance cameras" that could penetrate clouds and darkness. Photo interpreters, many of them women, specialized in particular geographic areas, weapons systems, or engineering types to the point where interpreting changes in their area became intuitive. One of Britain's most celebrated photointerpreters, Constance Babington-Smith, confirmed the existence of the German V-1 "Buzz Bomb" vengeance weapons, thus providing early warning of the terror attacks that were soon to befall Britain (Burrows 1986).

Geographers made important contributions to the war effort above and beyond the application of geotechnologies (Palka 2002). For example, regional geographers made substantive contributions to the war effort. The American military, on the eve of World War II, was not prepared to fight a global war in environments ranging from the desert to the Arctic. In 1941 the Army Quartermaster had only three standard issues of uniform and equipment—temperate, torrid, and frigid—with boundaries based on lines of latitude. Most of the geographers' effort was focused on the preparation of area intelligence studies that involved the military, economic, and administrative aspects of potential areas of operations. Reports for operations planning emphasized descriptions of topography, soils, vegetation, drainage, and the human elements of urban areas and transportation. Probably the finest examples of wartime reports were the Joint Army and Navy Intelligence Studies that were produced by a team of experts in various fields but were directed and coordinated by professional geographers (Russell et al. 1954, Palka 1995, Palka and Galgano 2000). Geomorphologists were instrumental in providing analysis of soils' trafficability for armored movement and beach suitability for amphibious assaults. All sides in the war relied on accurate weather information for ground and especially air operations (Bates and Fuller 1986). Military forces on both sides established weather stations throughout their areas of operation and even in meteorologically strategic places such as Greenland so as to be able to provide early warning of storms and accurate forecasts.

Perhaps the most critical decision of the war based on a weather forecast was General Dwight D. Eisenhower's D-Day decision. The Allied amphibious assault into Normandy was a momentous undertaking. The dawn landing required a combination of environmental conditions, including a low tide to reveal beach obstacles, three miles of visibility for naval gunfire support, clear skies for air support, a full moon to enhance a large-scale night-time airborne assault, calm seas for the landing craft, and a light wind to disperse smoke. These conditions needed to last at least 36 hours if not for several days.

Group Captain James M. Stagg of the Royal Air Force was appointed chief meteorological officer for Eisenhower's headquarters. His task was to provide accurate five-day forecasts, given this was the time needed for embarkation and transit of the massive force. His analysis, based on averaging weather data from previous years, showed that the necessary conditions were likely in only a few short windows in April, May, or June. The invasion was originally scheduled for May 1944, but due to force changes, it was postponed until June 4, 5, or 6. If the invasion did not occur during this time, the next window was not until June 19. On June 1, the weather appeared to be bad for an invasion with the possibility of an extratropical cyclone sweeping over the invasion area. Early on June 4, Eisenhower postponed the landing for a day. As the day progressed, Group Captain Stagg and his meteorologists recognized that the storm systems were turning north and that a following high-pressure cell would provide a 48-hour window. As Winters et al. describe in *Battling the Elements* (1998, 28),

> At 2130 on 4 June Group-Captain Stagg presented this information to General Eisenhower. Fifteen minutes later, about 30 hours before the first wave of troops would land on the beaches, Eisenhower ordered the landings to take place on 6 June. This decision involved tremendous responsibility and, no matter how the operation turned out, it would affect history in a most profound way.

Of course the invasion was a success, and on June 19 (the next invasion window), Normandy experienced the largest spring storm of 1944 (Winters et al. 1998).

A number of technologies that were not specifically geographic, but would prove invaluable to geographers at a later time, emerged during the Second World War. These included radar, sonar, and ballistic missiles. Gustav Herz discovered the existence of electromagnetic waves in 1888, but he attempted no practical application. In the years before World War I, there was some civil experimentation, but surprisingly there was no military research effort in World War I. The U.S., France, Germany, and the Soviet Union experimented with radar in the interwar years and made some rudimentary progress. Britain, however, was the first country to develop and field a practical air defense system based on radar. The "Chain Home" radar system coupled with the eight-gun fighter would ultimately assure Britain's survival in the Battle of Britain (Latham and Stobbs 1996, 1998). Radar technology developed rapidly during the war, and by 1945, Royal Air Force planes were using a rudimentary radar "camera" to obtain images at night and through clouds. This technology was the precursor to later technology that would prove invaluable to the remote sensing community. Another technology developed during the war was sonar, which used sound waves underwater rather than the reflected radio waves of radar. Sonar was used to detect vessels at sea, especially submarines. It is now a standard remote sensing technique in oceanography. The Germans developed the first ballistic missile as a terror weapon to wreak havoc on London in the Second Blitz. The V-2 was the precursor to both the Inter-Continental Ballistic Missiles (ICBM) with their nuclear payloads that would terrorize a generation and the rocket boosters that would later lift remote sensing satellites into space (Hartcup 2000).

5. THE COLD WAR

It did not take long after World War II for the former allies of the Soviet Union and those of the U.S. to set their sights on one another in a forty-year conflict that came to be known as the Cold War. A significant factor in keeping this Cold War predominantly cold was the geographic technology of overhead imagery intelligence or remote sensing. While vast strides in aerial photography, photogrammetry, and photo interpretation had been made in World War II, even greater technological achievements and military applications were to come.

By the early 1950s, the Cold War was well under way and the threat of nuclear war between the Soviet Union and the U.S. was a serious possibility. The U.S. Air Force, lacking good intelligence, posited that the Soviet Union had built a massive fleet of strategic bombers and thus a so-called "bomber gap" existed. They used this argument to circumvent President Dwight D. Eisenhower so as to convince the U.S. Congress of massive funding needs for a large increase in American nuclear bombers. Both the Air Force and the Central Intelligence Agency wanted new reconnaissance aircraft that could fly so high and far that they could spy on the Soviet Union with impunity. Eisenhower, not trusting the Air Force, gave this mission to the CIA, which with the help of the famous aeronautical engineer Kelly Johnson and his "Skunkworks," built the U2 spy plane.

The U2 was a marvel of engineering for its time. It could fly at 70,000 feet (21,212 meters) and it had a very long range. The U2's main camera set the standard for future reconnaissance cameras and was a quantum leap ahead of its World War II predecessors. A sophisticated system of precise image-movement compensation overcame the problem of vibration that had plagued all aerial cameras since World War I. This system took into account the motion of the plane, the vibration of its engine, and the movement of the new Kodak fast, high-sensitivity film. This compensation was essential to acquire clear pictures from such a high altitude. The system had 60 lines of resolution per millimeter and could distinguish objects the size of a basketball from 13 miles (21 km) high. The aircraft could also carry other sensor packages to include a radar imaging system. On July 4, 1956, a U2 flew a mission from Germany and passed over Moscow, Leningrad, and the Baltic coast. Over the next four years, the U2s would fly 20 deep-penetration missions over the Soviet Union and prove that there was no bomber or missile gap. In 1960 the Soviets finally succeeded in shooting down a U2 piloted by Francis Gary Powers. Eisenhower was forced to cancel the overflights, but a new technology emerged that made such dangerous flights unnecessary (Burrows 1985).

The U.S. military and intelligence communities knew that the U2 was vulnerable, and that one would eventually be shot down. Thus in conjunction with the Rand Corporation and other elements of the aeronautical and scientific communities, they began to study the feasibility of using the new ballistic missile technology to launch a surveillance device into orbit. The advent of the Soviet *Sputnik* program gave them added incentive. As usual, the Air Force and CIA had competing visions and fought a bureaucratic battle over technology and control. Eventually the first U.S. imagery intelligence satellites would emerge under the codename CORONA. This very expensive project sought to overcome substantial technical difficulties and would prove to be the basis for the subsequent civilian remote sensing systems such as LANDSAT that would follow some 13 years later. The CORONA Program was revolutionary but fraught with problems. In fact, the program suffered 12 mission failures from February 1959 until the first successful mission in August 1960 (Day et al. 1999).

The CORONA Program was comprised of six satellite models with three different intelligence objectives. In 1962 these satellites were given the codename "Keyhole" or KH for short. Keyhole systems referred to orbital platforms such as CORONA, while the code word "Talent" referred to suborbital systems such as the U2. The KH-1 through KH-6 satellites comprised the CORONA family. As Day and his colleagues note (1999, 7),

> CORONA achieved a number of notable firsts: first photoreconnaissance satellite; first recovery of an object from space (and first mid-air recovery of an object from

space); first mapping of the Earth from space; first stereo-optical data from space; and first program to fly more than 100 missions in space.

Most of the CORONA satellites were "bucket dumpers," meaning they returned their film to earth in capsules that were retrieved in mid-air by specially equipped Air Force cargo planes. The film was then developed on the ground and distributed to the various agencies. While the image quality was great (up to 12-inch spatial resolution), the time lag in delivery of the photos was long. The KH-5 LANYARD was equipped with a low-resolution videcon camera and radio-link transmitter that could beam the images back to a receiving station. This was a technology before its time as the images were of such poor quality as to be nearly worthless. The CORONA satellites were considered the first and second generation of imagery intelligence satellites (Burrows 1986; Day et al. 1999).

In August 1966, the third generation KH-7 and KH-8 "Gambit" systems came into service. The KH-7 and KH-8 worked in conjunction. The KH-7 was a low-resolution surveillance craft equipped with a Multi-Spectral Scanner (MSS) and a radio-link transmitter. Later KH-7s carried a Thematic Mapper device that had three times the spatial resolution of the MSS and operated in seven bands (blue, green, red, near infrared or IR, first mid-IR, second mid-IR, and far IR or thermal infrared—TIR). The single-band panchromatic images could be overlaid in various combinations to produce color images. The KH-8 was a close-look system used to examine targets of interest identified by the KH-7. KH-8s carried a long focal-length camera with a spatial resolution of six inches as well as a low-quality thermal imaging system, MSS, and TM. The KH-8s flew at very low altitudes (as low as 69 miles (112 km) which gave the camera a resolution of three to four inches) but had very short lifespans due to atmospheric drag. They carried two to four "buckets" for film return; some 752 were launched between 1966 and 1985 when they were retired. The second-generation systems were a significant improvement with their MSS and TM systems, but they were still primarily bucket dumpers and were limited to daylight imaging (Burrows 1986, FAS 1997).

In 1971, the fourth generation KH-9 Hexagon (known lovingly as the "Big Bird" because it was as large as a Greyhound bus) was placed into service. The Big Bird had a "folded" 20-foot focal-length mirror that took excellent pictures with a one-foot or better resolution. It also carried secondary TIR, MSS, and TM systems with a television download capability, and it could produce three-dimensional images. Most importantly, it carried a photomultiplier that intensified the available light, thus making this the first night-capable system. The Big Bird carried both low-resolution, large-area surveillance systems, and a high-resolution camera with several buckets, thereby merging the functions of the KH-7 and KH-8 into one platform

(Burrows 1986, FAS 1997). The Big Bird, however, was still a bucket dumper, which limited its life span, substantially increased its cost, and failed to provide the Holy Grail of "real time" intelligence.

The military and intelligence communities had come to rely on their eyes in the sky, but the systems were not adequately responsive in providing high-quality imagery in a timely fashion. What was needed was photo-quality imagery that could be telemetered back to earth. The answer came from the Bell Telephone Laboratories in 1970 with the invention of the Charged-Coupled Device or CCD. The CCD is a light-sensitive electronic device that senses and records the amount and wavelength of photons striking it. These values are recorded in digital format and then reassembled by a computer from a digital image. This digital data can be telemetered via radio back to an earth station where it is reassembled into an image (Burrows 1985). These images are manipulated by computer so as to be sharpened, error corrected, rectified to map coordinates, and classified. These techniques would become known as Digital Image Processing or DIP and would become a mainstay in the geographic techniques (Jensen 1996).

The first KH-11 "Kennan" or "Crystal" was launched in 1978. The platform carried new CCD-based digital sensors that included TM, MSS, TIR, and a photomultiplier light-intensification system. The system could also produce three-dimensional images, but the spatial resolution of the sensors remained a closely guarded secret. Various sources suggest the KH-11 could clearly image a license plate from space, giving it a one-inch or less resolution. The most important KH-11 feature was its ability to telemeter its data to the ground, thus precluding the need for buckets and substantially increasing the lifespan of the satellite (an important consideration given a KH-11 cost about $1 billion). The KH-11s carried a large amount of hydrazine maneuvering fuel, giving them a service life of about three years. Depending on their maneuvering, some lasted much longer—up to a decade (Burrows 1985; FAS 1997; Lindgren 2000).

The significance of imagery intelligence in preventing World War III should not be underestimated. From the earliest contentions of a "bomber gap" in the 1950s and the latter "missile gap" in the 1960s, the spy planes and satellites gave leaders on both sides the confidence that they were not facing a "nuclear Pearl Harbor." Indeed the capability to see and verify the number, type, and location of enemy missiles, planes, tanks, and other weapons made the concepts of arms control and arms reduction possible, thus stopping the nuclear arms race, reducing nuclear arsenals, and diminishing the threat of global thermonuclear war (Peebles 1997; Day et al. 1999; Lindgren 2000).

The advancement in remote sensing brought about by the CORONA systems were matched by CORONA's contribution to both American military and civilian mapmaking. CORONA's images from space forced the military Mapping, Charting, and Geodesy (MC&G) community to develop entirely new systems and methods to deal with this fantastic data source. The CORONA data also necessitated an entirely new geodetic control system, and prompted a number of geography departments across the country (starting with Ohio State University, which imported an entire geodesy faculty from Europe) to offer courses in the new technologies, thus expanding the realm of the geotechnics. As the U.S. Geological Survey (USGS) became involved with CORONA, it was able to revise its maps of the U.S. in a rapid and cost-effective manner while improving the organization's technical skills.

The Cold War brought about a number of other innovations that would have a great impact on civil geographic techniques, including thermal imaging, laser range finding, the Internet, digital mapping, and the Global Positioning System. Thermal imaging devices were developed early-on for airborne platforms, but became important tools for ground combat. By the early 1980s, main battle tanks in western armies were outfitted with sophisticated thermal imaging systems, which when slaved to the tank cannon, became thermal sights. Thermals are used as the primary fire control mode because they can image targets through darkness, smoke, and dust. Thermal imaging systems found later use in many civil applications (see Hodgson and Jensen's chapter in this volume).

Laser range finders were another military technology installed on tanks in the early 1980s. A laser beam is bounced off a target and reflects back to the sensor. A computer then determines the range based on the elapsed time. While laser range finders have uses in engineering, extensions of this technology such as LIDAR (Light Detection and Ranging—basically radar with light instead of microwaves) and Laser Induced Fluorescence (LIF) are remote sensing systems used in the geotechniques (Lillesand and Kiefer 1994).

The Internet, which has arguably revolutionized how we communicate and work, began as the ARPANET, a project of the Defense Advanced Research Projects Agency (DARPA). ARPANET was a Cold War effort to interlink defense, industry, and academic research computers in such a way that the system would automatically reroute data around any damaged elements or the network. The idea was for the network to be robust enough to survive any level of attack up to a nuclear strike. The net eventually evolved far beyond what its developers had intended into the Internet and World Wide Web of today. The Internet and Web have had a major impact on how geographers conduct research, and how we acquire, store, analyze, and distribute spatial data products from the geotechniques. Military planners, operators, and staff sections regularly tap into a whole range of databases within the public domain in order to develop and support operational decisions. This practice has become increasingly widespread, effective, and efficient, thanks to the Internet. Examples include USGS, NOAA (National Oceanic and Atmospheric Administration), ESRI, NIMA (National Image and Mapping Agency), UN, CIA, PRB (Population Reference Bureau), CDC (Center for Disease Control), U.S. Census Bureau, climate sites, etc.

The advent of precision-guided munitions ranging from ICBM to cruise missiles was predicated on the possession of extremely accurate earth data. The need for such data spurred the early CORONA earth-mapping missions. Early cruise missiles were a boon to the military because of their accuracy and the fact that human pilots were not at risk. These early-version cruise missiles used a terrain-following radar that matches the missiles' position with a digital map. Thus digital mapping of most of the world became an important task for the military, as these data were essential for new generations of precision weapons (Larson and Pelletiere 1989). The Defense Mapping Agency (which later merged into NIMA) put great emphasis on digital mapping of the world, and made much of these data and techniques available to the USGS and the geotechnical community (Larson and Pelletiere 1989).

The predecessor to the NAVSTAR GPS was the U.S. Navy's TRANSIT navigation system designed to accurately locate ballistic missile submarines and surface vessels. TRANSIT consisted of four satellites, was slow and prone to error, but it did open the era of satellite navigation systems. The Air Force began work on a multisatellite navigation system in 1963 and after years of testing and modifications, launched the first NAVSTAR satellite in 1978. The GPS operated today by the Air Force has 24 operational satellites that provide precise around-the-clock, all weather, three-dimensional navigation information. While the system is owned and maintained by the military, civilian use of GPS has blossomed (see Hodgson and Jensen's chapter).

6. POST-COLD WAR ERA

Technologically, the post-Cold War Era has been an extension of the Cold War. Advances in satellite reconnaissance systems to include radar satellites and the weaponization of GPS are two major trends. The leveraging of information technology to include GIS, geographic visualization, and use of the Internet/WWW as an information delivery system also are trends worth noting. There has been a significant change, however, in the relationship between civil developments of geographic technology and military applications.

Prior to the end of the Cold War, military requirements, research, and application drove much of the cutting-edge research in the geotechniques. The impacts of the World Wars and the Cold War on cartography, aerial photography, photo interpretation, and satellite imaging are well-documented. In the post-Cold War Era, however, the relationship has been reversed. While each of the military services has its own research and development components (R & D), none is in the business of fully developing technologies, equipment, ordnance, etc. The services articulate a "needed capability," and private corporations attempt to satisfy the needs of the potentially lucrative customer. It is the private sector that has made rapid advances in information processing technologies for civilian use that the U.S. military looks to for developing cost-effective, off-the-shelf solutions to suit military needs. We have evolved to the point where the military relies more than ever on outsourcing. Meanwhile, "beltway bandits," defense contractors, and megacorporations around the country have filled their ranks with former military personnel in order to gain ties to the services and acquire insights regarding "projected capabilities." As such, the private corporations are usually ahead of the military's R&D community in developing technologies, systems, and equipment. The former "shop around" their products early-on in the development process with hopes of acquiring interest and feedback, and landing a multimillion (or billion) dollar contact, or better yet, a succession of contracts. The corporation may in turn subcontract services and components related to the main product. Thus military procurement processes have blossomed dramatically in recent years and have major cultural/social/political implications in the U.S.

Computers and computer software are a major case in point. Years of development by the various armed services have produced a plethora of information systems that are obsolete, expensive, and that will not interface with each other. The solution has been to adopt industry-standard off-the-shelf products such as personal computers and the Microsoft Windows operating systems. Fueling this trend has been increasing reliance on contracted services. While the military has developed specialized systems in the post-Cold War Era, they are often based on civil and/or commercial systems.

In terms of post-Cold War satellite reconnaissance systems, the military-intelligence community advanced two major systems. The KH-12 or Improved Crystal is a military version of the Hubble Space Telescope. It is highly classified, but the Federation of American Scientists (FAS) believes it has improved electrooptical sensor systems; some reports speculate it can image a postage stamp. A major feature of this platform is that it was designed for deployment by the space shuttle, and it can be refueled in space by the shuttle, thus giving it a very long operational life. It is also highly maneuverable since fuel consumption is no longer the limiting factor, and it can operate at multiple altitudes, indicating it is a very versatile system.

All of the camera or electrooptical imaging satellites, however, share a major drawback. They cannot image through clouds, smoke, or dust. While side-looking airborne radar (SLAR) has been an option in aircraft, the U.S. sent up the first dedicated radar imaging satellite in 1988. The Lacrosse or Onyx satellites launched in 1988, 1991, and 1997 can see through darkness, clouds, smoke, and dust using synthetic aperture radar (SAR, a type also used on the space shuttle). FAS estimates that Lacrosse has a maximum spatial resolution of about one meter, but that the satellite can vary its resolution to cover large areas or to zoom in (FAS 2002).

The first post-Cold War conflict to confront the American military was the Persian Gulf War of 1990-91. Geotechnology played a very important role in this war especially in terms of remote sensing, precision-guided weaponry, early use of GIS, and widespread use of GPS down to small-unit level. Satellite imagery played a critical role in the Gulf War, especially in the defensive buildup phase of Desert Shield when aircraft could not overfly Iraq. The U.S. had KH-11 and Lacrosse satellites available. Of interest is that the Coalition purchased large amounts of LANDSAT and SPOT commercial imagery to supplement their own systems. They also purchased all the commercial imagery so the Iraqis could not buy it. The satellites provided thousands of images that supported the threat estimation and targeting effort and the preparation of the land, air, and sea war plans. The U.S. also deployed two E-8A Joint Surveillance and Target Attack Radar Systems (JSTARS) aircraft. The JSTARS was still in development but was rushed to the war. JSTARS uses a multimode SLAR with a very high resolution. It flies 50-70 miles (80-113 km) behind the front and can provide information on vehicle location, number, and movement over an area of 30,000 sq. mi. (77,700 sq. km.). Another interesting remote-sensing innovation was the first widespread use of Unmanned Aerial Vehicles (UAVs) equipped with video cameras that beamed back images of enemy areas for tactical intelligence and targeting purposes. A major lesson from the Gulf War was that satellite imagery was critical, but that it was not timely enough and adequately available to help battlefield commanders plan and make decisions. After the war, the call went out for smaller, less expensive and more versatile satellites that could meet the needs of the military (Cordesman and Wagner 1996).

The Gulf War was one of the first conflicts to make extensive use of precision-guided munitions launched from aircraft, surface ships, and even submarines. Aircraft used laser and television-guided bombs and missiles, while conventionally armed cruise missiles launched hundreds of miles from their targets used terrain-following radar and digital earth data to find their targets. Three-dimensional terrain visualization came of age in 1995 during the NATO air campaign over Bosnia. The U.S. Air Force introduced a computer system called PowerScene that modeled the terrain of Bosnia including target areas and enemy air defense sites. Aircrews could virtually fly through their missions and see the terrain before ever sitting in a cockpit. PowerScene helped to improve the accuracy of bombing raids (thus reducing civilian casualties) and reduced the risk to the aircrews, as they were familiar with the hazardous terrain and location of enemy defenses. PowerScene was later used to great effect in the Dayton Peace Accord negotiations where leaders from Serbia, Croatia, and Bosnia were able to visualize the impact of their boundary negotiations by "flying" the border in PowerScene (Corson and Minghi 1996).

During the U.S. war in Afghanistan, there were a number of geotechnology uses. One involved the use of UAV technology, which was enhanced by robust communications links that enabled one to identify a target in an otherwise remote or inaccessible location, follow it or conduct surveillance, decide when and where to interdict it, attack it (with either ordnance carried by the UAV or another platform), and acquire battle-damage assessment, all in real time and on a wide-screen display within a command and control facility. A much simpler form of technology, also used during the Afghanistan war, was the use of the chat room concept to report information from lower units to higher headquarters. This technique enabled rapid dissemination of information as opposed to the traditional "stove-piping" of radio communication up and down the chain of command in an inefficient (and sometimes ineffective) fashion. A third area involved the use of virtual 3-D maps, as opposed to traditional paper maps, during the planning process for a tactical mission. Despite advancements in mapmaking, 2-dimensional maps still require the user to develop a 3-D mental image of the terrain, which may require extensive training and/or years of experience. The 3-D renditions, however, make it possible for all users to identify and focus on relief variability, vantage points, natural routes and corridors, etc. Programs such as FALCON VIEW were especially beneficial to ground forces and staffs, and simplified the detailed planning of flight routes, air assaults, tactical operations, communications, logistics, and supporting fires. Finally, munitions and robotics were designed and used in concert with geological and geographical information to target and exploit specific types of caves that were used by Al Qaeda. The nature of the cave, especially composition (that is, granite vs. limestone or schist), depth, and the extent of the underground network posed challenges that were addressed by these emerging technologies.

Some early use of GIS for battle management and control also made their debut in the Gulf War and were fully operational in the Afghanistan and Iraq missions. The systems would eventually become coupled with GPS and communications systems to provide digital command and control systems.

The role of GIS in "battlespace management" is covered later in the discussion of the revolution in military affairs.

Global Positioning Systems proved extremely effective and popular during this period. It is very difficult to navigate in the desert (especially at night) due to a lack of landmarks to orient a map. The U.S. Army used a number of navigational systems including the maritime LORAN system to orient their formations. Those units fortunate enough to have GPS receivers found them invaluable for navigation and for locating the enemy in order to call for artillery or air strikes. Troops were so enamored with the technology that they wrote home asking family members to purchase civilian receivers to send to them in the desert, as there were not nearly enough military issue units to go around. The military procured many commercial receivers under an emergency procurement action, but these commercial receivers were not "crypto-capable" or rugged enough for military use (DOD 1992).

By the late 1990s, GPS was adapted as a guidance system for precision-guided munitions (Air Force New Service 1998). Second-generation cruise missiles were fitted with a GPS receiver, in addition to terrain following radar, thus increasing their accuracy. Precision-guided bombs that use laser or television guidance requiring terminal guidance to the target have degraded capability in bad weather. The introduction of the inexpensive Joint Direct Attack Munition (JDAM) tailkit enabled the U.S. military to transform its large inventory of 1000 and 2000-pound general purpose "dumb bombs" into GPS guided precision weapons. The JDAM is a kit for conventional bombs consisting of an inertial navigation system/GPS guidance kit and steering "strakes" that enable the weapon to be launched from up to 15 miles (24 km) from the target in all weather. The bomb is a "fire and forget" weapon in that once launched, it needs no further input from the aircraft as it will follow its GPS coordinates (if the GPS loses signal the inertial navigation system takes over) to hit within 13 meters (43 feet) of the target. The weaponization of GPS is significant to the American military, because the large stock of Vietnam-era dumb bombs can be turned into precision-guided munitions. This fact means that far fewer aircraft can effectively attack far more targets in all weather, day or night, thus reducing the risk to aircrews, and the risk of unintended civilian casualties (and/or collateral damage) (FAS 2002).

In the decade since the Gulf War, geographic technologies have continued to play an important role in military activities, but the trend of the military adopting technology produced by the civilian sector is even more pronounced. This is especially true in the area of GIS, which is gaining increasing military acceptance across the spectrum from peacetime garrison operations to conventional warfare.

The military spends most of its time in garrison or in training areas. The U.S. military has adopted GIS for a range of tasks to include facilities management on its many bases and the environmental protection of its limited training areas (Chang 2002). After early attempts to develop in-house GIS solutions (e.g., the U.S. Army Corps of Engineers GRASS GIS), the U.S. military increasingly uses commercial off-the-shelf GIS solutions to manage its hundreds of installations and millions of acres of land.

The U.S. Army Training and Doctrine Command (TRADOC) is responsible for training the American Army on 16 installations housing 150,000 people on two million acres of land. TRADOC, supported by a contractor, developed a GIS-based decision support system known as the BASOPS Corporate Database. This system connects all 16 installations and interfaces with other DOD systems; it contains more than 450 map and aerial photographic data layers plus data from other federal, state, and local agencies. The system enables analysts to collaborate across the network to develop recommendations to help decisionmakers solve problems (ESRI 2001a, 2001b, 2001c).

Computer simulations are also used in training as well as during "real world" operations. One of the major benefits that is often overlooked is their contribution to conserving resources (ammunition, vehicle or aircraft miles, fuel, wear and tear on equipment, training lands, and perhaps most of all, time). Simulations can enhance decisionmaking at all echelons and in a variety of situations. They also can provide training opportunities for individuals as well as units, and they can facilitate resource management.

Peacetime military training causes extensive damage to the military's limited training lands. The Army developed the Integrated Training Area Management (ITAM) system to overcome the apparent conflict between force readiness and environmental stewardship. The ITAM system consists of four components: Land Condition Trend Analysis (LCTA), Training Requirements Integration (TRI), Land Rehabilitation and Maintenance (LRAM), and Environmental Awareness (EA). The LCTA is a land-use decision support GIS that tracks the use of training lands and identifies when lands require rest or restoration. The other systems interface with the LCTA to provide training requirements and land restoration methods (the EA module is a means to educate users on their environmental stewardship responsibilities). The ITAM system is the major method for ensuring that training and environmental stewardship are properly balanced (DA 2002).

GIS is finding increasing use in humanitarian and peacekeeping operations. Early efforts to use GIS in Bosnia were expanded for the Kosovo mission. The Kosovo Force (KFOR) headquarters in Pristina had a multinational staff of military cartographers and GIS analysts available to provide custom maps and GIS products to the multinational force. An example application was the use of GIS to analyze the distribution and cleanup of landmines in the province. Mine Action Centers in each of the Multi-National Brigade Headquarters tracked the location of minefields and unexploded ordnance, logged the detection of new hazards, and tracked the nature and progress of demining operations. Another GIS application (used by nongovernmental institutions in support of the International Criminal Tribunal for the Former Yugoslavia) in Kosovo was the War Crimes Documentation Database developed by the Illinois Institute of Technology's Inter-Professional Studies Program. This project consists of a traditional database documenting war crimes linked to locational information. The information on war crimes is compared with information on troop movements to both validate the integrity of the evidence and assist prosecutors in identifying suspected perpetrators (Atkins 2001).

Digital maps are increasingly used in the U.S. military. The Force XXI experiment involved equipping combat vehicles and headquarters units with digital map displays, which when coupled with GPS and secure data and voice communications, enabled commanders and vehicle crews to see the same battlefield picture of friendly and enemy locations. The actual use of GIS analytical capabilities is in the early stages of experimentation and implementation.

The military logistics community is also leveraging information technology and GIS to improve their operations. This development is especially true in the transportation community, which plays a key role in deploying forces from bases in the continental U.S. to hotspots around the world. As an example, the Military Traffic Management Command's Transportation Engineering Agency (TEA) maintains GIS databases on strategic seaports, military installations, the National Highway Planning Network, National Bridge Inventory, National Railway Network, and strategic highway and railway networks. The TEA uses sophisticated transportation analytical models to determine transportation infrastructure capabilities and requirements. The TEA is working on a system to make this information available to users over the World Wide Web (Corbley 2000).

The military transportation community also uses a number of systems to track cargo through the transportation system. In the ocean transportation system, equipment is loaded on ships using the Improved Computerized Deployment System or ICODES, which is essentially a GIS that has the layout and dimensions for each deck and hold of strategic sealift ships. The system also contains digital templates of all military vehicles and cargo that might be transported. The number and types of vehicles to be transported are collected at the origin and electronically forwarded to ICODES, which then creates an optimum stow plan for each hold of each ship. This capability dramatically reduces the time it takes to load a ship. The World Wide Port System (WPS) tracks the specific location of each piece of cargo and reports this information to the Global Transportation Network (GTN). This system provides in-transit visibility and accountability of all cargo. The U.S. Air Force has a similar system for the optimal loading of transport planes. These systems are critical in ensuring optimum utilization of very limited transport assets and the accountability of billions of dollars of equipment and supplies (Corson 2000).

7. THE REVOLUTION IN MILITARY AFFAIRS

The experience of the Persian Gulf War of 1991 and the recent military operations in Afghanistan and Iraq led a number of commentators to suggests that we were or soon would be experiencing a "Revolution in Military Affairs" (RMA). Such revolutions have occurred in the past with the advent of gunpowder, railroad transportation, and the aircraft carrier. This one, however, is predicated on the idea that a rapid pace of technological innovation is altering the nature of modern warfare and the basic foundations of security (Martel 2001). Michael O'Hanlon (2002, 83) of the Brookings Institution explains:

> Due to the excellent performance of American high-technology weapons in the 1991 Persian Gulf War, as well as the phenomenal pace of innovation in the modern computer industry, many defense analysts have posited that a revolution in military affairs (RMA) is either imminent or already under way. The RMA thesis holds that further advances in precision munitions, real-time data dissemination, and other modern technologies, together with associated changes in war-fighting organizations and doctrines, can help transform the nature of future war and with it the size and structure of the U.S. military. RMA proponents believe that military technology, and the resultant potential for radically new types of war-fighting tactics and strategies is advancing at a rate unrivaled since the 1920s through 1940s when blitzkrieg, aircraft carriers, large scale amphibious and airborne assault, ballistic missiles, strategic bombing, and nuclear weapons were developed.

Barry Schneider (1995, 43) of the Air War College defines RMA as "a fundamental change, or discontinuity, in the way military strategy and operations have been planned and conducted." He suggests that RMAs are driven by technological innovations such as nuclear weapons at the end of World War II, operational innovations such as the German blitzkrieg, societal changes such as Napoleon's conscripted national army, or a combination of developments. Many defense analysts argue that we have been in the midst of an integrated RMA since the start of the Gulf War and that it is accelerating and becoming a mature system that integrates logistical, organizational, and technological capabilities across all the operational mediums of sea, land, and air. New warfare applications areas are emerging including long-range precision strikes, information warfare, dominating maneuver, and space warfare (Schneider 1995). A review of these new warfare areas shows that geography and geotechnology are integral and essential to all of them with perhaps the exception of information warfare.

Long-range precision strike is the ability to locate high-value enemy targets and destroy them quickly while causing minimal collateral damage. The U.S. has been a leader in this area since early efforts with laser-guided bombs in the Vietnam War. The Gulf War was characterized by substantial use of precision-guided munitions (PGM), and while the PGMs got most of the press coverage, the majority of the bombs dropped were the unguided "dumb" bombs of previous conflicts. In contrast, precision-guided munitions were extensively used in Afghanistan and Iraq to target terrorist threats, while reducing the collateral damage and casualties among non-combatants.

The NATO air campaign against Serbia in 1999 (Kosovo Crisis) was the first true application of PGMs as the dominant weapon. The essence of the precision strike is to detect the enemy deep in their rear areas, recognize their concept and strategic plan, and select and prioritize the critical targets to attack. These attacks must be synchronized in time and space to deal a devastating blow from which the enemy will not easily recover. Since Operation Desert Storm, U.S. commanders have had continuous wide-area surveillance and target acquisition systems with capabilities that continue to evolve (McKitrick et al. 1995). These surveillance and target acquisition systems are based on remote-sensing technologies discussed earlier such as orbital and aerial imagery, data from JSTARS aircraft, and data from unmanned aerial vehicles. The precision-strike munitions are also based on geographic technologies to an ever-greater extent. Cruise missiles use terrain-following radar that compares the return against a digital map, and later models have a GPS guidance system as well. The JDAM mentioned earlier makes large stocks of conventional bombs available as PGMs and overcomes the limitations of laser and other guidance systems from weather or limited visibility situations.

Maneuverability has always been a critical element of warfare. The ability to reposition forces globally or locally, on a much compressed time scale, and with highly lethal but greatly reduced forces, is the potential of this new warfare area. Dominating maneuver is defined as the positioning of forces—in coordination with the other three warfare areas—to attack decisive points, destroy the enemy's center of gravity, and attain the war objectives (McKitrick et al. 1995). Dominating maneuver is predicated on identifying the enemy's center of gravity and understanding where to position forces to render the enemy position untenable. Remote sensing is an essential tool in identifying enemy dispositions and thus their center of gravity. Cartographic data of the world, GPS, and GIS analytical tools are all essential in repositioning the forces. The transportation automation tools described earlier that facilitate rapid strategic mobility are a critical element in this new warfare area.

Space warfare is the exploitation of the space environment to conduct full-spectrum, near-real-time, global military operations. The U.S. military relies to a great extent on space-based systems during its daily operations. Space operations currently support earth-bound forces with satellites that enable communications, remote sensing, timing, and navigation. Future antisatellite weapons, an orbiting missile defense system, space strike systems that can hit targets on earth, and transatmospheric transports have the potential to expand the realm of space operations as did the fighters, bombers, and transport planes of the Second World War. Because orbital dynamics require operating speeds of about 17,000 miles (27,350 km) per hour, space operations will occur an order of magnitude faster than traditional air operations. Once again these envisioned technologies would rely on the geotechnologies of remote sensing and GPS at a minimum. There may ultimately be a role for GIS and cartography as well (imagine mapping and spatial analysis on the Moon or Mars).

A major area of the RMA that is maturing today is the use of information technology in automating command, control, and communications systems. The ultimate goal has been characterized as information dominance (Libicki 1997) or dominant battlespace awareness (DBA) (McKitrick et al. 1995). Both of these concepts are fundamentally based on geography and geographic technologies.

It should be borne in mind that one of the ultimate goals for geotechniques within the military is to provide total situational awareness for unit commanders at all echelons. Various systems, as noted above, already contribute to this goal to a limited degree. The objective is to have real-time knowledge of the enemy, terrain, weather, and the location and disposition of all friendly forces in order to command and control operations, to facilitate coordination and changes to the plan when the unexpected occurs, to avoid fratricide, and to minimize collateral damage. Research in this area will continue for the foreseeable future because of the major communications and compatibility changes that exist between systems. Information capacities and capabilities are related to the geotechniques being developed and adopted.

The concept of information dominance is defined as superiority in the generation, manipulation, and use of information sufficient to afford its possessors *military* dominance. It can be analyzed in terms of command and control, intelligence, and information warfare. Much of the U.S. military's investment in information technologies is focused on improving knowledge of *where* and *when*. The U.S. Army Force XXI project envisions outfitting every fighting vehicle with information systems that have digital maps. GPS linked to radios keep the maps updated with the current location of all friendly forces. Remote-sensing systems such as Predator UAVs along with reports from scouts and combat units identify the location and activity of enemy units, which are automatically updated on the digital map display in every vehicle. Staff officers can use various analytical tools (to include spatial analytical tools such as terrain analysis software) to develop plans. Operations orders and the accompanying graphics can be sent directly to the digital map displays in every combat vehicle. This concept was tested by a brigade of the 4th Mechanized Infantry Division at the National Training Center in the Mojave Desert of California in 1997. Observers reported that operations could be planned and carried out in half the time. The U.S. Navy and Air Force are working on similar concepts (Libicki 1997).

Dominant Battlespace Awareness (DBA) envisions total information dominance over an enemy. A military force would know where the enemy is, what it is doing, what it intends to do, and where its critical points are. It would deny the enemy this information about itself. The implications of DBA are significant. The ability to target the enemy with long-range precision-strike weapons might enable the bulk of forces to stand off and thus minimize casualties. The DBA also implies the power to do more with less. If the DBA can reveal where the main enemy attack is coming from, it may be possible to defeat them with a smaller force that will not have to cover a large front. Much lighter forces such as air assault or amphibious forces might also be used. These maneuvers would be less risky because planners could select landing sites they know to be free of enemy forces. Finally, a smaller DBA-enabled force might launch a successful counterattack sooner because they would know the path of least resistance and could focus fire support and reserves at the critical time and place (McKitrick et al. 1995).

The DBA and information dominance ideas are certainly not yet mature, but they have demonstrated potential. Consider the lessons of using special operations forces (SOF) along with remote-sensing systems to identify key targets, then having the SOF call in air strikes that used PGMs to destroy enemy forces with minimum firepower and collateral damage. These concepts have been used extensively in Afghanistan and Iraq, but they continue to evolve and may prove to be even more and more important in future conflicts.

It bears mention that not all technological innovations have to be cost-prohibitive to have an impact on performance. In attempting to improve the cultural awareness of U.S. troops destined for Afghanistan, Iraq, and North Korea (recognizing that approximately 35,000 troops have been postured south of the DMZ for more than fifty years), the geography faculty at the U.S. Military Academy prepared three separate handbooks with accompanying CD ROMs (Palka 2001; Malinowski 2002; Palka and Galgano 2003). Each of these are nothing more than focused regional geographies, made possible by information-gathering technologies, GIS, and mapmaking and publishing software. The CD ROMs provide an e-book, along with digital maps, and a program that enables one to select a route between two points and experience an actual fly-through. The idea was to enhance unit and staff preparation and mission effectiveness by providing deploying units with increased cultural awareness about the people of the country (friendly or otherwise) and a preview of the terrain and climate prior to their arrival. The idea for these three publications stemmed from the knowledge that other geographers had made during wartime, such as contribution to the JANIS books or the Admiralty Handbooks in the U.K. (see Palka 1995, 2002). In this case, however, technology facilitated the production of user-friendly references in an extremely short amount of time and at a minimal cost.

The key issue for the geographer in these ongoing discussions is the recognition of the role of geographic technologies. The command and control systems associated with these concepts have at their very core digital terrain data that are cartographic representations. Identifying the position of friendly forces is based on GPS technology. Detection and reporting on enemy forces, especially at long range, relies more than ever on the use of remote-sensing systems, whether they be satellites, aircraft, UAVs, or ground sensors. Spatial analysis as embodied in GIS has great potential but has seen limited use to date.

The potential to leverage spatial analysis for battlefield use at various scales is enormous. Military intelligence officers could use GIS spatial analysis tools for what the U.S. Army calls intelligence preparation of the battlefield (IPB). This includes determining avenues of approach (mobility corridors), templating enemy forces based on their doctrine (until the remote sensing systems determine their actual location), and developing likely enemy courses of action based on terrain, weather, and enemy capabilities and intent. Operations planners could use spatial analysis to develop and war game their plans, conduct intervisibility studies, determine time lines based on distance and terrain, and for many other tasks. Logisticians could use site selection tools to locate their logistics bases, and route optimization tools to maximize the use of their limited transportation resources. As all of these data are digital, they could be transmitted to the digital map displays in subordinate headquarters and combat vehicles in far less time than traditional methods. The U.S. military is a leader in this area, but has only conducted some rudimentary experiments. The potential of the combination of GIS spatial analysis, remote sensing, and GPS overlaid on digital maps is very significant to the RMA.

Most of the components of the RMA rely to some extent on geographic technologies, thus geography and geotechnologies, whether done by professional geographers or someone else, will play a key role. Presumably, professional geographers in government, industry, and the military will make significant contributions. It remains to be seen if academic geographers will play any role in the development of these concepts and technologies and thus have any voice or influence on how the RMA develops.

8. CONCLUSION

This chapter has described how military activities and warfare have both affected and been affected by the evolution of geographic technology. Military requirements have had a major impact on the development of the geographic technologies of cartography, remote sensing, GPS, and GIS. Cartography was employed early-on to provide military maps, and many of the advances in topographic mapping were in response to the needs of improved artillery. Cartography continued to serve and advance with the two World Wars and was forced to develop entirely new approaches with the advent of CORONA satellite imagery. These great strides were translated into gains for the civilian population of the U.S. through maps produced by the USGS. These maps were significantly improved by the contributions of both aerial photography and the CORONA satellite images.

Aerial photography, airphoto analysis, and photogrammetry were born with the advent of the airplane and came of age in the two World Wars when military necessity prompted tremendous technological innovation. Generations of photo interpreters would go on to apply their skills in civilian endeavors after both wars. The techniques pioneered in the military form the basis of modern academic programs in aerial photo interpretation and photogrammetry.

Satellite remote sensing was born because of the Cold War need to prevent a "nuclear Pearl Harbor." The sensors that would eventually become standard on LANDSAT and SPOT satellites were invented, tested, and perfected for a decade in the Keyhole series of U.S. imaging satellites. CORONA and its successors not only helped prevent World War III, but they provided the basis for civil satellite programs, and recently declassified imagery is a treasure trove for scientists utilizing change detection procedures. In addition, the need for trained geodesists in the CORONA program prompted American academic geography programs to begin formal training programs, which formed the basis of for much of our automated geographic technology training programs.

The Global Positioning System is a military initiative that has become a critical technology in civil life. GPS has revolutionized many fields to include surveying and mapping, aerial and marine navigation, and even fishing.

In the late Cold War and post-Cold War eras, however, we have seen a shift. The military has pursued lower cost, off-the-shelf information technologies. GIS in particular has come into widespread military use, but now it is the commercial providers that are showing the military how to use existing commercial products for military applications. The military has embraced GIS for a broad range of functions ranging from environmental management of military training lands to battlefield analysis (Chang et al. 2002)

Geography and military activities always have been intimately linked. Every soldier is a geographer at heart and must understand and appreciate terrain, weather, climate, and the human environments in which they operate. Geographic technology has always been critical to soldiers in that maps tell them where they are, where the enemy is, and where they must go. Other geographic technologies are an extension of these functions. Geography and geotechnology will play a critical role in any so-called revolution in military affairs. If history is any guide, then military systems and approaches that are derived from future revolutions in military affairs may spur the geotechniques into new directions and facilitate the development of new ones.

Finally, applications of geographic information, tools, and techniques are arguably just as important during peacetime and military operations other than war (MOOTW) as during wartime. Technologies used to support missions within the peacetime and MOOTW arenas include humanitarian assistance, land use management, protection of endangered species, management of water resources, responding to natural disasters, and fighting forest fires. These are causes that we consider socially responsible uses of geotechniques developed to solve military problems (Palka 1995, 2000, 2002).

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