Terrain Analysis:  
Historical Perspective and Future Direction 

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A Research Paper submitted to the Department of Geography in partial fulfillment of the requirements for the degree of Master of Science 

April 1986
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CHAPTER 1
INTRODUCTION

Problem and Purpose

Since the beginning of human history, geographic information has been an important component of military conflict. By its very nature, warfare is geographic: wars occur in places and places define unique physical environments and climates. Wars are a complex three-dimensional array of actions and reactions extending from the battle front all the way back to the source of logistic resupply. In essence, warfare involves time, distance, and the physical nature of what exists within the confines of that time and distance. Down through the centuries the geographic nature of warfare has been obvious to military scientists, tacticians, and strategists; however, it was only during the present century that the distinct subfields of Military Geography and Terrain Analysis could be identified. As 20th century warfare has evolved in complexity through two World Wars, countless revolutions, and the explosive growth in military technology, it has become impossible for one military commander, or even a military staff, to keep pace with the ever increasing demands for accurate and timely geographic information. While recognizing that "weather and terrain have more impact on battle than any other physical factor, including weapons, equipment or supplies", the U.S. Army (1982a) also has recognized that a manual storage/retrieval system is not sufficient. Today's modern battlefield will present more demands for meaningful terrain information, than can be collected, processed, and disseminated in a timely manner.

Albeit modern technology is the culprit in generating this growing reliance on more and faster terrain information, technology is also presenting some possible solutions. While the lethality and mobility of warfare has increased, there has been a corresponding explosion in computer and information related technology. The Department of Defense, and specifically the U.S. Army, has begun to pour great quantities of money into the research and development of computer based analysis and storage/retrieval systems.
The purpose of this study is to review the historical development of the central ideas of military geography and terrain analysis and to examine these new research initiatives from that perspective. Although the mobility and technological aspects of warfare have changed rapidly, the essential geographic nature of warfare has remained constant. In some respects, modern military scientists are even more dependent upon terrain and weather information in order to gain the upper hand on the battlefield. As the defense establishment rushes to fill the very real need for improved geographic analysis, several questions arise: Are the new information and terrain analysis systems being driven by technology itself or by real and historically valid needs? In the long term, are important gaps being left in terrain analysis capabilities within the defense establishment? Is it reasonable and feasible to expect computer systems to replace, in some measure, what has historically been accomplished through manual terrain analysis?

Definitions

Military Geography. In the broadest sense, military geography is any geography which can find application in the complex military sciences of armies, navies, and air forces. It is difficult to imagine any branch of geography which does not have some military application in time of war. Wars involve people's needs and behaviors and thus are related to all aspects of human and social geography; wars often start over economic or resource issues and thus are related to those geographic fields; and finally wars are fought on the surface of the earth within the physical confines defined by climatology and physical geography.

For the purposes of this discussion, the definition of military geography will be limited to include those studies within the field of geography in which the investigator has in mind a military application or purpose. Such studies can be different in their approach. For example, suppose a military planner is interested in the results of a soil study in a particular region. If he were to turn to a physical geographer outside the military community who is studying the properties and distribution of soils in that region, he might not find all the information he is looking for. Perhaps the soil strength or other engineering properties, of vital importance to
the military planner, would not be included in his study. Similarly, although every military officer is called on to heed geographical considerations in planning strategy, tactics, or logistics, not every officer is qualified as a geographer nor does every officer understand the benefits of geographic techniques. Thus it follows that military geography is applied geography done for military purposes and at the same time it is also military science using geographic methods or techniques. It follows that military geography is done by those professional geographers who are given a military problem or application to study or by those within the military who have geographic training. It could also be said that military geography is done best by those with both military and geographic training.

In order to expound the definition further, the term "military application" requires some further clarification. One does not have to condone war in order to recognize that military battles and wars are the ultimate applications of military geography. Because wars are geographical in nature, one cannot separate a military operation from the environment or geographic conditions which make up the area of conflict. Any geography involves the study of properties and differences of places and regions. Going one step further, military geography then looks at the ways "...in which the efficiency of military activities [war] or the solution of military problems is influenced because the places are different." (Peltier and Pearcy, 1966) "Military geography involves the whole range of geographic research as it is applied in particular places, and the success of any given undertaking depends in considerable measure on the flexibility with which military principles are adjusted to the natural and cultural conditions existing in specific strategic and tactical situations" (Russell, 1954).

**Terrain Analysis.** This field is best thought of as a subfield of military geography. The word "terrain" refers to the physical nature of the surface of the earth--namely the soils, slopes, vegetation, and hydrologic features each of which are subject to the pervasive influence of climate and weather. The U.S. Army Field Manual 30-10, *Military Geographic Intelligence (Terrain)*, emphasizes the military application of terrain information in its definition: "...the process of analyses of a geographical area to determine the effect of the natural and man-made
features on military operations. It includes the influence of climate on these features." (U.S. Army, 1972). This definition includes the urban, industrial, and other cultural landscape features through use of the term "man-made features". Thus terrain analysis is more than simply the natural aspects of military geography. It is concerned with all aspects of the landscape (natural and man-made) which either enhance or detract from enemy or friendly military success. On the other hand, it can be distinguished from military geography in its scope. While military geography deals with the broad spectrum of foreign policy, political, strategic, and tactical geographical considerations, terrain analysis is limited to the more specific aspects of tactical considerations.

More recently, an increasing reliance upon airmobile weapons delivery systems has necessitated the inclusion of vertical depth to the battlefield. The first 4 or 5 thousand feet above the surface of the ground must be included in the definition of terrain. Line of sight visibility, fog and haze conditions, and air density are critical to battlefield commanders.

The term terrain analysis system is used in this paper to refer to any system by which information about the physical environment is collected, analyzed, stored, retrieved, and further synthesized for use by military commanders in battle planning and subsequent decisions regarding the conduct of the battles themselves.

Military Geographic Intelligence. This is the product of terrain analysis. It is terrain information which has been interpreted in relation to its effect on personnel, equipment and material. Field Manual 30-10 indicates that geographic intelligence is "...terrain information which is independently meaningful and can be utilized directly in support of operations, or has potential value for future operations." (U.S. Army, 1972). It is important to distinguish between information (raw data) and intelligence (processed information). The terms geographic intelligence and terrain intelligence are used synonymously.
CHAPTER 2
HISTORICAL PERSPECTIVE

Military Terrain Analysis—Historical Examples

While the disciplines of terrain analysis and military geography have only recently been recognized and defined, the geographical and terrain considerations of warfare are as old as history (warfare) itself. There were no geographers to analyze the terrain in the 10,000 man Athenian army that rushed to defend Athens on the Plains of Marathon in 490 B.C. However, as the Athenian generals stood discussing battle plans on the slopes overlooking the encamped Persian army of Darius the Great on the landing beaches below, the terrain considerations were certainly foremost in their minds. On the other hand, the 26,000 strong Persian army appeared to have disregarded the terrain factors by their decision to land and encamp on the plains of Marathon. The Persians had their backs to the sea, mountains to their front, and rivers and marshes on both sides. Thus, when the Athenians attacked, the Persians had little room to maneuver their cavalry around the flanks; they ended up in a double envelopment and on the losing side of a complete rout: 6400 Persians killed, 192 Athenians dead.

Ten years later, in 480 B.C., Xerxes, the Persian successor to Darius the Great, arrived with his mighty army to once again attempt to bring Athens to submission. Xerxes came overland with an army of 150,000 men in concert with a naval force of 4200 ships. Being greatly outnumbered, the Athenians at least had the opportunity to apply some military geography and choose their point of defense for the land battle. Considering the terrain once again, the Athenians chose to defend themselves with a small covering force at the narrow defile at Thermopylae. Because most of the Athenians were tied up in fighting the naval battle, only 7000 Spartan troops were placed in this pass to hold off 150,000. This seemingly impossible task was attempted along a 1/2 mile front with the sea on one side and the steep mountains on the other. The Spartans held off the mighty Persian Army for days until a Greek traitor told the Persians of a road through the mountains, whereupon they conducted a night
march and surprised the Spartans from behind. The Persians won the land battle that day but lost the naval battle that followed and were really never able to bring Macedonia and Greece under their dominion. Thus one sees that the effective use or ignorance of terrain information had an effect on even the most ancient battles.

A study of more recent military history likewise reveals the geographical nature of warfare. Napoleon introduced the concept of mobility in overcoming the problem of time and distance. In 1796, he overcame great obstacles of terrain and weather by pushing his army in a swift march over the Alps into Italy to surprise and overwhelm the Sardinian and Austrian armies. Ignoring the former concept of the importance of an army's base of operation, Napoleon established a mobility in warfare that was a precursor of more contemporary principles which were developed after the introduction of wheel and tracked vehicles.

Undoubtedly it was second nature for these generals to consider the terrain in their planning; they didn't need the academic discipline of geography to tell them what was intuitively obvious. Nonetheless, the mobility and complexity of warfare, hinted at by Napoleon's quick strikes, and yet to emerge from the industrial revolution, seems to have begged for a military geographic field. A Swiss writer on the nature of war and sometime advisor to Napoleon, General Antoine Jomini, attempted to develop some universal principles upon which all warfare depended. In the fourteenth chapter of his book *Traité des grandes opérations militaires*, Jomini wrote of a commander's need to be influenced by geographic considerations in his choice of a line of operations (Brinton, Craig, and Gilbert, 1944). Thus we find the first hints of the development of the academic field of military geography with its subsequent subfield of terrain analysis.

19th Century Roots for Military Geography

It was only during the 19th century that the academic discipline of geography and its sub-discipline of military geography began to separate from the mainstream of general science. Figure 1 portrays the developmental sequence of geography, military geography and
Figure 1. Graphic portrayal of development of Military Geography and Terrain Analysis up to the events of World War II. The strong influence of military science and historical events is depicted by the bold vertical arrow at right.
ultimately terrain analysis. Humbolt, Ritter, Vidal del la Blanche, Peschel, Richthofen, and Ratzel laid the foundation for the discipline of geography in Europe, while Marsh, Maurey, Powell, and Semple, among others, built on this foundation in America (Holt-Jensen, 1980). The close relationship between political and military geography was important in the early stages of development. Clausewitz, the great German military thinker of the early 19th century, described war as only a means to political ends: "War is nothing else than the continuation of state policy by different means ...do the political relations between different peoples and governments ever cease when the exchange of diplomatic notes has ceased? Is not war only a different method of expressing their thoughts, different in writing and language?" (Clausewitz, On War, quoted in Rothfels, 1944). This definition binds geography to politics: politicians use war as a means and war depends on geographic analysis to solve complex problems of time and distance.

While Napoleon achieved mobility by bold, rapid marches, the Prussians of the late 19th century began to see the value of the railroad in overcoming the geographic problem of time and distance. In 1866, the Prussian General Moltke, who studied under the geographer Carl Ritter, achieved success over an Austrian army, which was in many ways superior, because he used the rails to mass his troops at the last minute at the decisive point of battle (Holborn, 1944). Subsequently, the first geographic professorships of Europe were established in the German Empire during the 1870's, and were based on a perceived political/military need for geographic study. James (1972) states that the Franco-Prussian War of 1870-71 was one of the prime motivations for establishing these geographic professors. Consequently, it can be said that the roots of military geography are closely linked to the roots of German academic geography. They both derived, in part, from the military and political climate of the 19th century.

Having established the connection between political and military geography, it is necessary to go one step further and discuss the developmental role of geopolitics in this process. The field of geopolitics is distinct from political geography. Geopolitics is by
definition the use (and abuse) of the findings of geography and political geography in the arena of practical politics. Friedrich Ratzel played an important role in the development of geopolitics as well as military geography. Like his predecessor, Clausewitz, Ratzel saw the important connection between war, geography, and politics. Although one should not make the mistake of calling Ratzel a geopolitician, he did contribute to the field with his deterministic views and his analogy of the state as an organism. His views were later taken out of context in order to justify certain political ends. Although it now seems clear that he never intended this analogy of the state as a living organism to be taken literally, others used it in their pseudoscientific geography to justify the Lebensraum (living space) concept upon which Nazi Germany's nationalist policies of the 1930's and 40's were based (James, 1972). Similarily, Ellsworth Huntington used Ratzel's environmental determinism to justify the idea of superior and inferior races. A very prolific writer, Huntington's ideas were very influential on both sides of the Atlantic; it is apparent that he strongly influenced the racist quality of Nazi thought. The Heartland concept by British geographer, Mackinder, was also adapted by the German geopoliticians who were bent on its service to the interests of Germany.

The defeat of Germany during World War I only served to strengthen the German geopolitical resolve to use all means of restoring Germany as an international power. The use of geography for nationalistic and political purposes was often very subtle; the government supported and funded geographic research and surveys. It was often only a short step to where the geographic information became political propaganda. "Geopolitics was groomed to bring geography to the service of a militarized Germany. Its functions were to collect geographic information, to orient it to serve the purposes of the government, and to present some of it to the public in the form of propaganda." (Whittlesey, 1944) German propagandists used cartographic skill to their advantage: By using bold arrows to portray menacing intentions of neighbors, they contributed to the geopolitical effort to win the hearts of the public to their cause (O'Sullivan and Miller, 1983). The chief apostle of geopolitics in Germany was Karl Haushofer, a Bavarian military aristocrat, who picked up on Mackinder's writings and began
to publish a geopolitical magazine in 1924. He was involved in the early forming of the Nazi party and appears to have been influential in the writing of Hitler's *Mein Kampf* (O'Sullivan and Miller, 1983).

Although there exists a geopolitical thread in many of the early German publications or perhaps a geopolitical motivation behind them (they were not reviewed beyond their titles for this paper), one should not assume that they were necessarily geopolitical in nature. One of the results, however, of the German government's involvement in the field of geography, was that military geography became prominent first in Germany. Peltier's (1962) bibliography of military geography demonstrates the German lead in the early years. One can get a feeling for the timing of the development of various military geographic subjects by observing a listing of all the publications of journal articles and books by category and by year of publication (figure 2). The reader must keep in mind that this listing is not a complete listing of all military geography articles; rather it should be considered a very good sample from which some limited conclusions can be drawn. German authors dominated publications in the general military geographical field as well as military geology and some of the less published topics such as military hydrology, military transportation/communication geography, and political military geography. The timing of these publications is significant: the first surge coming right before and during World War I and the second occurring in the 1930's when Hitler rose to political power.

**Military Geography During World War I**

While military geography developed in Europe under German influence during the late 19th and early 20th centuries, it was not until World War I that this field began to find practical use on the battlefield on a large scale. This period also marked the first interest of the the American geographic community in military geography. Prior to this, the great western surveys were focused on resource inventory within our own country. The Great War provided the first large scale military application; many U.S. geographers volunteered or were asked by
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Figure 2. Frequency and timing of Military Geographic publications by category from 1909-1961. Each box represents publication of one book or journal article. The dark boxes (●) represent German publications whereas the white boxes (●) represent all other publications. (data from Peltier, 1962)
their government to channel their studies into the war effort. William Morris Davis did a regional study of France for U.S. troops while Douglas Johnson studied the relationship between strategy and topography in the battlefields of the war (Johnson, 1917). Additionally, Johnson as well as other geographers were asked to participate in the process of redefining international borders in the aftermath of the war.

During this period, most of the military geography was related to the systematic sciences or was descriptive in nature. Figure 1 portrays military geography branching into the systematic and descriptive categories with strong influence from the discipline of physical geography. The demands from the military scientists of WWI also played a significant part. The descriptive nature of this early military geography is evident in a listing of military geographic titles in the Geographical Review 1916-1922:

- The Balkan Campaign (1916)
- The Great Russian Retreat (1916)
- The Conquest of Rumania (1917)
- A Note on the Guarani Invasion of the Inca Empire (1917)
- The Balkans, Macedonia, and the War (1918)
- Military Campaigns Against the Germans in Africa (1918)
- Some Recent Books on Military Geography (1920)
- Military Meteorology (1922)

All but the last two titles deal with some aspect of the European war (or a previous military operation in the case of the Inca). These articles are more than just cursory descriptions. The first three, all by Douglas W. Johnson, include geographical descriptions of the landforms, roads, soils, and weather and relate these descriptions as to their effect on the various battles described. In referring to Johnson's book *Battlefield of the World War*, James (1972) describes Johnson as making "...the first substantial contribution by an American to military geography". However, Johnson's *Battlefield* (1921) was not his first contribution considering he also published a substantial volume on military geography in 1917 entitled, *Topography and Strategy in the War*. These works were written at a time when it was thought that technology in the forms of long range artillery, machine guns, automatic rifles, and motorized vehicles would make terrain considerations obsolete. In Johnson's words from the introduction to his
latter book: "What protection is a river channel when the modern military engineer can throw bridges across it in a few hours, defended by artillery which can reach the enemy many miles beyond the bank?" (Johnson, 1921) However, Johnson goes on to conclusively demonstrate that such technological advancements do not negate the importance of the terrain. In both of his books he follows a format in which he first describes the physical nature of the terrain followed by a description of the battles and how they were influenced by the terrain. The important connections between the physical aspects of terrain and battlefield success were in this manner established early and would have an effect on the later development of terrain analysis.

In addition to the historical and descriptive aspects of early military geography just mentioned, the systematic sciences were also very active in what could be termed systematic military geography. This rather all inclusive term is meant to include all those areas of systematic science which are done with a military geographical perspective. A full listing of systematic subject headings used by Peltier in his Bibliography of Military Geography (1962) is at Appendix A. It is interesting to note such esoteric subjects as military botany and military geophysics. Military geology has been one of the most important of the military systematic disciplines as indicated by the frequency of publication in that subject (figure 2). Geology was used by both sides during the first world war in the planning for and drainage of the extensive trench works of the front. Johnson (1921) reports that British geologists were consulted in the battle of Flanders in 1916 in order to dig under the small but domineering terrain of several small hills. These "mines" were packed with explosives and the tops of the hills were literally blown off in order to neutralize the defenders and capture the high ground. Other applications of military geology are the location and exploitation of rock and minerals for engineering and industrial purposes. These applications continue to the present day.

The recognized value of applied geology and physical geography during World War I, marked the beginning of systematic military geography in the United States. The need to train more people in military geology and geography was apparently one of the great lessons of the
war. It was at this time that the War Department, through the Committee on Education and Special Training, put out a circular which included this statement: "The branches of earth science which contribute most directly to military need are Military Geology and Geography including Meteorology and Military Mapping". This was sent to colleges and universities around the country with the recommendation that some courses in these subjects be taught at each institution where geography or geology was already being taught. When many requests for help with these courses arrived, the National Research Council commissioned its Division of Geology and Geography to write a textbook: *Military Geology and Topography* (Gregory, 1918). This book is a classic treatment of military geography covering the following subject material: rocks and earth materials; rock weathering; streams; lakes and swamps; water supply; landforms; map reading and map interpretation; and economic relations and military uses of minerals. The importance of this work is underscored when one realizes that the principles outlined in the book are very applicable today. The authors did not make specific military applications with reference to the military technology of the day, but chose to make general military applications which have yet to be dated.

The relationship between military geography and the world wars is perhaps most obvious when one looks at the publication frequency of military geographic articles during this century. Figures 3.a. and 3.b. show the number of articles with military geographic topics in relation to other subjects in the journals, *Geographical Review* and *Annals of the AAG*. In the year 1916 the *Annals* was dominated by military geography--the only article was the presidential address entitled "Meteorology and War-Flying"! The president of the AAG that year, Robert De C. Ward, explains that most of the membership was directly or indirectly in government service and the war effort and so it was not possible to have the normal amount of papers read and published. This was the only year that a presidential address of the AAG dealt with military geography. The clustering of these subjects around both of the World Wars demonstrates the motivating factor the wars have had in directing geographic interest towards military geography.

![Chart showing the number of Military Geographic articles per year from 1911 to 1980.](chart1)


![Chart showing the number of Military Geographic articles per year from 1916 to 1985.](chart2)

Figure 3. Number of Military Geographic articles in relation to total number of articles published in *The Annals of the AAG* and *The Geographical Review*. Note the clustering of military geographic articles around the world wars.
Military Geography During World War II

In the same way that the systematic and descriptive branches of military geography emerged from the experience of World War I, topical and regional military geography emerged from the Second World War (as graphically portrayed in figure 1). The new demands for further geographic studies can be traced to the wide range of non-European geographical conditions encountered during this conflict. Prior to this, the isolationist attitude of the majority of the United States precluded much consideration of fighting in foreign environments. World War I was not really foreign because the European battlefields were not very unique in terms of topography and climate. America's wartime experiences in the 1940's, together with the emergence of the U.S. as a world power, changed the American world view. The American military machine suddenly found itself fighting in arctic environments in its own Aleutian Islands at the same time in the tropical beaches and atolls of the South Pacific. Military leaders had not been trained to think in terms of climatic and environmental effects. The very real need for geographic terrain analysis was best demonstrated when General Brown, selected to lead an attack force on the Japanese in the Aleutian Islands, trained his soldiers in the Mojave Desert and then took them to fight the Japanese in Alaska's Aleutian Islands with smooth soled, low topped leather boots! Needless to say he was relieved shortly before the attack began (Naske, 1985).

The field of topical military geography resulted from this clearly defined military need for a more world-wide geographical analysis. While systematic sciences were emphasized in military training after WWI, it was not until the late 1940's that this emphasis began to emerge in the form of new military doctrine. In defining topical military geography, Peltier and Pearcy (1966) say that "...topical military geography accounts for the differences in doctrine imposed by different environmental conditions such as in arctic, mountain, amphibious, desert, urban, or forest operations". A list of subject headings that Peltier considered topical military geography is included in Appendix A. This branch of military geography is most likely done
by military officers and other members of the military community. Topical military geography is closely tied to military science. The conclusions from topical studies such as tactical or logistical geography, are applied to the way the Army fights or how efficient its supply operations are.

Just as the Second World War spread the vision of military geographers beyond North America and into topical studies, it also focused the need for more regional studies (Stone, 1979). Regional military geography is described by Peltier and Pearcy (1966) as a synthesizer of all the various branches of geography as they might apply to a particular region. One can trace the regional school to the foundation laid by Vidal de la Blanche in France (Holt-Jensen, 1980). However, there was very little regional emphasis in military geography until the world wars. Using Peltier's military geography bibliography (1962) once again as a measure of subject frequency, one finds 177 regional articles published before 1961; of these only 34 were published before 1940. Most of these were British and German. The early British emphasis on regional military geography stemmed from her global empire. Most of the German regional articles were published in Zeitschrift für Geopolitik, the geopolitical organ edited by Haushofer himself. Whether one considers these regional or geopolitical depends on one’s point of view.

In any case, regional geography was not well established in U.S. military thought prior to World War II. At the outbreak of this war, and as the United States came closer to involvement, the various government agencies responsible for the collection of intelligence began to assemble teams of geographers in order to do regional and other geographical studies. Handbooks were prepared for many different areas of the world. These placed special emphasis on descriptions of the landforms, soils, vegetation, drainage, roads, transportation facilities, cities, and climate. Russell (1954) states that the Joint Army and Navy Intelligence Studies (JANIS) were some of the finest examples of professional wartime reports. These studies were systematic in their approach: soil scientists did the soil studies, meteorologists did the climate and so on. However in most cases it was a geographer who synthesized, coordinated, and edited the final report. These were apparently true multi-disciplinary teams
which produced high quality regional geography. Such special terrain reports were precursors to the more contemporary terrain studies.

Several technological innovations during the period between the world wars had far-reaching impact on military geography and terrain analysis. Although the first wartime aerial photographs were taken during the American Civil War (from a balloon), it was not until WWII that the development of high altitude aircraft platforms coincided with the development of good aerial cameras and films. This made the collection of vast amounts of geographic data feasible and practical and gave birth to the field of remote sensing. This ability to remotely collect geographic data, to be interpreted and analyzed later in an office environment, was critical to the allied war effort. Aerial photographs were crucial in strategic target selection and damage assessment; analysis of landing beaches; mapping of tropical vegetation; selection of routes; planning of defenses; and many other similar applications.

Post War Development of Terrain Analysis

The emergence of terrain analysis as a separate field of military geography took place in the years after the war. Military geography continued as a strong academic and military discipline in the United States. It is interesting to note that while Germany was the leader in publishing military geography before and during the world wars, the situation was reversed after the war. Peltier's bibliography (1962) shows no German publication on the various military geographical subjects after 1943 (see figure 2). There are probably two reasons for this: some German geographers left Germany after the war and, secondly, those that stayed shied away from military subjects due to the Nazi stigma.

After the war, a synthesis of geographic analysis began to emerge under the title terrain analysis. While the four sub-fields of military geography already described have continued to the present, the subfield of terrain analysis borrowed components from each of these fields in forming the basis for the comprehensive field of terrain analysis. Terrain analysis needed the systematic sciences in order to collect and interpret terrain information; descriptive military
geography showed the critical nature of terrain and validated the need for better prediction of terrain influences; topical military geography gave specific applications for terrain analysis in the fields of military doctrine, clothing, and equipment; and finally, regional military geography formed the structure around which terrain can be appreciated in its total geographic setting.

Since the Second World War, topical military geography has continued to develop. The military literature on the various types of tactical fighting has blossomed such that now one can find a field manual on just about every conceivable environmental situation. Geographers have played a key role in developing these manuals. The list of operations manuals includes: airborne operations, guerrilla operations, infiltration operations, barrier and denial operations, armor operations, airmobile operations, snow and cold weather operations, desert operations, jungle operations, mountain operations, amphibious operations, and military operations in urban terrain (to name a few)! Furthermore, topical military geographers, studying the geographical and environmental aspects of tropical and jungle warfare, were the ones who impacted the design of clothing and equipment to withstand the heat and humidity of Vietnam. The war in Southeast Asia during the 60's concentrated a great deal of topical geographic study. Although tank warfare was not important during this conflict, it provided the impetus to study track vehicle movements through various soils and jungle vegetation types. As already mentioned, clothing and equipment had to be modified. Tactics from the Korean war, which had been effective against the Chinese there, had to be modified to fit the environment of Vietnam.

However, the field of terrain analysis, as defined for this paper, did not become established from the war in SW Asia or directly from topical military geography. Within geographic academia, the concept of possibilism and the quantitative revolution had a significant impact on the formation and direction of terrain analysis within the broader field of military geography. This influence is graphically represented on the left side of the flow chart in figure 1. The essential unknowability or inability of man to be able to predict anything in his environment takes us back to possibilism and the probability notion (in contrast to
environmental determinism). Although one may not be able to know for sure what will happen, the door is still open to make certain possible guesses as to outcome. Furthermore, one can often estimate the chances of an event occurring. "In military geography the introduction of the probability notion relates to estimating the chance of occurrence of an event or encountering natural or man-made things. It further relates to the chance that a given direction is the one calling for movement or in which to look for the enemy. Moreover, it may be the chance that certain events and circumstances exist in combination." (Peltier and Pearcy, 1966) This is the essence of terrain analysis as used in the U.S. Army today. By means of quantitative methods one is able to make reasonable estimates of the outcome of certain geographical conditions.

Further impact of the quantitative revolution on military geography can be seen by referring back to the year of publication of various subjects from Peltier's bibliography in figure 2 on page 10 (1962). One can see a significant rise during the 1950's and 60's in the number of publications for several of the systematic military geographic categories. Subjects which use quantitative methods, such as hydrology, climatology and meteorology, show this rise in publication frequency (figure 2a). The corresponding rise in military geomorphology was largely due to the new interest in quantitative geomorphology. Eight out of 23 military geomorphological publications between 1953 and 1961 have quantitative aspects included in their titles. Included are such titles as Objective Field Sampling of Physical Terrain Properties and A Mathematical Model of Terrain Shielding. Similarly, the military geographic methodology titles shown in the late 50's and early 60's (the second category in figure 2b) are almost all quantitative in nature. The quantitative influence within the discipline of geography, helped to make feasible the study of terrain features with the intention of making predictions concerning friendly or enemy mobility or counter-mobility.

While these concepts were developing within the geographic community, the U.S military community was moving rather slowly towards a unified doctrine of terrain analysis. Although terrain analysis was used extensively during the Second World War, much of the
Army's expertise took off their uniforms or left government service at the end of the war. As already noted, much of the post war geographic study was concentrated on developing tactics, clothing and equipment for the world's physiographic regions. Following the war, the responsibility for gathering geographic information and intelligence was with the CIA, the DIA, and the Army's intelligence and topographic communities. The role of CIA and DIA, arising out of the wartime agency Office of Strategic Services (OSS), was largely in the realm of strategic, regional, and political geography, while the Army concentrated most of their efforts into cartographic production through the Army Map Service (AMS) with some geographic analysis done by the Topographic Branch, Military Intelligence Service (Stone, 1972).

The general outline of terrain analysis development is depicted in figure 4 (essentially a continuation of figure 1). The major shifts in doctrine, organization, and hardware which were important to terrain analysis have been charted for the last four decades, including the present one. In general, the terrain analysis doctrines have become more specific in application, the organizations implementing this doctrine have become smaller in scale (from Department of Defense to Army Divisions), and the hardware, after thirty years of little growth, has begun to develop in the 1980's.

During the 1950's, terrain analysis was simply another component of the Army intelligence community. Most studies were a carryover from the regional emphasis of WWII. They were largely strategic in scope and were conducted by higher level staffs within the Department of Defense. A good example of this type of strategic terrain study occurred during the Korean conflict of the early 1950's. Tomlinson (1967) discusses the strong dependence on precise terrain information that resulted in General MacArthur's successful invasion at Inchon. In order to gain approval of his risky invasion plan he had to overcome the geographical criticisms from experts working for the Joint Chiefs of Staff. MacArthur's plan was to arrive in the shallow waters of Inchon harbor at a time which coincided precisely with one of the exceptionally high tides. Such a landing would have been impossible on all but four dates
Figure 4. Development of Terrain Analysis since World War II. This chart is essentially a continuation of the chart in figure 1.
during the year in which the tide was high enough. Strategic surprise was achieved because the North Korean People's Army did not consider such an invasion route to be feasible. However, this type of analysis was done at the Army staff levels.

Following the Korean War and into the 1960's, a great deal of theoretical research in terrain analysis and methodology was done at Waterways Experiment Station (WES), Vicksburg, Mississippi and at Engineer Topographic Laboratories (ETL), Ft. Belvoir, Virginia. Terrain studies were done by the Army Map Service and Army Topographic staff elements, but such studies were limited in scope and general usage. Although computers were used extensively in research, the state-of-the-art hardware which was in the field at this time consisted of a collection of aerial photo interpretation tools collectively known as the Tactical Imagery Interpretation Facility (TIIF). Furthermore, the Vietnam War did not provide a definitive need for detailed terrain analysis: understanding and using guerrilla tactics was perhaps more important than analyzing the terrain; the topolcal lowlands, rice paddies and mountain highlands were relatively consistent in terrain features; and the emphasis on air warfare and the absence of tank warfare precluded a large demand for terrain analysis. Accordingly, as the Vietnam War drew to a close, there was a renewed focus on conventional warfare, the NATO defense of Europe, and consequently on terrain analysis.

However, it was not the defense of Europe that really provided the impetus for increased emphasis and training in terrain analysis. The Arab-Israeli conflicts of 1967 and 1973, with their high speed armor tactics and closely coordinated air interdiction of airfields, were perhaps the most important factors in impressing the military establishment with the necessity of a quick response geographic information and intelligence capability. Shoemaker (1968) describes the quick success of the Israeli Air Force in the 1967 war as resulting in large measure from accurate intelligence information regarding the location of the most vulnerable of United Arab Republic's airfields and aircraft as well as a "precise understanding of time and space factors". The U.S. Army began the first steps to formalize its terrain analysis program at a lower organizational level in the early 70's, in part, because it was recognized that NATO would
never achieve tank for tank parity with Warsaw Pact forces. Terrain intelligence was viewed as the force equalizer or combat multiplier. Given good quality terrain intelligence which was both flexible and rapidly retrievable, an outnumbered force could expect to defend itself successfully. This was and still is the basic justification for a tactical terrain analysis system.

Definitive doctrinal statements and procedural guides were published: FM 30-10 Military Geographic Intelligence (Terrain) (1972), FM 21-33 Terrain Analysis (1978), and the ETL series of Terrain Analysis Procedural Guides (begun in 1979). This time period saw the development of a concept known as Intelligence Preparation of the Battlefield (IPB). With IPB, terrain information, along with other intelligence about the enemy, is processed in an attempt to predict with reasonable accuracy what routes and courses of action the enemy will take.

The Defense Mapping Agency (DMA), formed in part from the AMS in 1972, as well as ETL, were active during the 1970's in developing a terrain analysis data base which could be synthesized and manipulated by trained soldiers in order to produce terrain products which were meaningful and usable by military commanders. The result was the adoption of DMA's Tactical Terrain Analysis Data Base (TTADB) at a scale of 1:50,000. Additionally, a planning data base was also defined at 1:250,000. This data base consists of six thematic overlays: 1) surface configuration or slope; 2) vegetation; 3) surface materials or soils; 4) surface drainage; 5) transportation; and 6) obstacles (DMA, 1982). The system was designed so that, given these six elements of the data base, the Army terrain analyst could produce a wide variety of terrain intelligence products which would meet the commanders needs on the battlefield as depicted in figure 5. This process will be discussed in more detail in the next section. DMA was given primary responsibility for producing this data base; however, Army terrain analysts have also produced a significant amount of this geographic data in order to fill in the gaps in their areas of responsibility. Producing these overlays is a tedious manual process of viewing aerial photographs in stereo, studying landform patterns, making measurements, conducting field checks for ground truth if possible, and researching published material.
overlay for a heavily forested region may take as long as two man-weeks to finish. Although efforts are being made to complete this data base worldwide, in reality it will probably never be completed at a scale of 1:50,000. With the constant need for updating, it is only feasible to be able to keep a current data base for the present world's hot spots.

During the 1970's this terrain data base was introduced into the Army in the topographic battalions at the Theater Army level. Later in the decade, terrain teams were formed in support of each Combat Corps and Division. During this period, equipment to assist in analysis and synthesis of terrain information and to support the hard copy output of these terrain teams was assembled and placed in specially designed air-conditioned trailer modules. This equipment, collectively referred to as Topographic Support System (TSS), never made it to the field until the early 1980's, when it was largely obsolete. The primary reasons for the delay were threefold: the first and probably the foremost reason was the annual budget struggle to get on the priority "funded" list; secondly the hesitancy for Corps Commanders to add additional
electromagnetic signature and camouflage problems to an already crowded Corps tactical
operations center; and finally, since tractors were not provided with the trailer vans, they placed
demands on already scarce transportation assets. The addition of TSS modules were designed
to give a 48 hour response time to map revisions and terrain overlay requests.

By the end of the 1970's, the Army topographic community found itself wanting for
hardware to match its developing topographic doctrines and organizations. Referring back to
figure 4 under the hardware column, the "state of the art" at the end of the decade was the
Photo-interpretation Kit and the Zoom Transfer Scope. The computer modeling and
quantitative studies done during the 60's occurred in Army laboratories, and thus do not reflect
the Army's field capability.
CHAPTER 3
IMPLICATIONS OF TECHNOLOGY ON TERRAIN ANALYSIS

Technology and Terrain Analysis

Up to this point the significance of technological progress on the field of terrain analysis has only been suggested. At first glance it seems intuitive that the spatial limitations of terrain could be overcome by the advancement of technology. However, the issue is complex. Consider the time period at the turn of the century. Automotive and rail transport were certainly faster than horses. But were they more mobile? Only on their respective roadways and railways. Which is easier to maintain in a logistical sense, the horse or the automobile? During the days when automotive power was being introduced, the horse was probably easier to maintain; the horse could obtain food and water as he traveled, whereas the auto engine required the extra fuel, oil, and spare parts to be transported. In our urbanized society today, the horse would have the disadvantage. The point is that new technology often brings with it new logistical and geographic considerations.

The issue of the terrain/technology relationship was noted by Douglas W. Johnson 64 years ago: "It is an ever-recurring question, for each 'revolution' in methods of combat brings in its train a body of opinion intent on demonstrating that, under the new conditions of fighting, topographic obstacles have lost their significance, strategic gateways no longer exist, and commanding positions no longer 'command'. Then, as opposing forces share in the new discoveries, or profit in equal measure by new systems, each side maneuvers for an advantageous position on the terrain as one of the prerequisites to victory in battle" (1921). He goes on to emphasize the cardinal nature of terrain considerations as independent from technology levels.

Accordingly, the introduction of the tank did not give any long term advantage to either side during either world war, although the technologically superior German tanks can be given credit for a significant part in numerous individual battles. Although the initial advantage of the
tank was evident in the German Blitzkrieg advances through eastern Europe and Russia (whose forces had no tanks to speak of), in the final analysis, it was the vagaries of weather and the extended logistical channels which ultimately brought defeat to the Germans on the eastern front. In Southeast Asia the Vietcong and North Vietnamese achieved considerable success over "superior" U.S. forces by effectively utilizing the concealment offered by the the dense jungle vegetation. More recently, the Soviet Union's involvement in Afghanistan has proven once again that the terrain considerations (in this case the rugged Afghan mountains) can hold their own against superior armament and firepower.

Although improved weapons and vehicles of war have indeed changed some of the terrain considerations, the great equalizer is still the terrain and weather. Friend and foe must both experience the same mud, cold, slopes, or whatever. The timelessness of terrain considerations is best demonstrated by a quote from a U.S. Army Corps of Engineers manual entitled, *Topography, Map Reading, and Reconnaissance.* Under the heading "River Crossing" it states: "If a crossing is to be made in the face of the enemy, the location selected must fit the tactical situation; that condition being complied with, choose the location which will require the least labor and material to render it practicable. Fords should not be more than 4 1/2 feet [in depth] for Cavalry...the nature of the stream bottom is most important. It should give good footing and should not scour under the action of wheels and hoofs" (U.S. Army, 1917). The point being that these exact same words are applicable to the Armored Cavalry of today. The fording depth of most tanks is about 4 1/2 feet, and the nature of the stream bottom is still critical as a good foundation for the tank track pads. The river is a similar obstacle to both horse and tank alike.

Putting this in perspective, it appears that technology tends to balance out over the years. On the other hand, physical terrain and weather, while presenting equal faces to both sides in a conflict, give the advantage to the side which is able to gather and utilize the most military geographical information. The advantage goes to the side which can anticipate the effects of weather, reinforce natural terrain obstacles to his benefit, and anticipate the enemy's action
based on geographical constraints.

The aforementioned examples, while showing terrain considerations as being independent from technology levels, do not show the complete picture. While there are examples which show the minimum impact of technology, there are also examples which show the opposite. Indeed, while the jungle vegetation of Vietnam was a disadvantage to U.S. forces, it was technological innovation in the form of the helicopter which helped to overcome that disadvantage with increased mobility and flexibility. Today, in a similar fashion, the Soviet Union's forces are countering the Afgan rebel's terrain advantage with increased use of helicopter gun ships. New technology has provided increased mobility, speed, weapons, lethality, and range. However each of these has its price and unfortunately the price is often dependence on even more terrain factors. For example: machines need constant maintenance and logistics; increased speed means more rivers to cross and therefore more mobile bridging; heavy tanks require bigger bridges; more and bigger bridges require more trucks for transport; more trucks need constant maintenance and logistics support; and so on goes the inflation spiral.

The Modern Battlefield—the Fourth Dimension

In general, we can conclude that technological innovation begets new terrain considerations which in turn begets other new technologies. For example, the invention of the airplane brought the third dimension to warfare. As air power became integrated into the battlefield subsequent to WWI, the geographic considerations of time and distance were given a vertical component. It was natural for air delivered weapons, navigation systems, jet power, and rockets to follow. Later, helicopters added more flexibility to this third dimension. During the 1960's, significant strides in the application of electromagnetic energy gave birth to what could be termed the fourth dimension to warfare: electronic warfare. Electronic warfare is perhaps the most significant of all technological advancements in terms of terrain considerations. The atmosphere itself is an environment. The components of this environment
include: the surface features which may interfere with line-of-sight; the density of the air in relation to parachute and helicopter loading; the clarity of the air in terms of scattering, absorbing, or transmitting electromagnetic radiation; and intentional electromagnetic interference known as jamming.

During the last two decades, electronic warfare has become more and more sophisticated. Weapon systems use a variety of electromagnetic schemes to include laser guidance systems, homing devices which read various electromagnetic signatures, "terrain reading" radar systems, as well as a whole range of corresponding countermeasures. Lubkin (1986) has couched the lethality of today’s electronic air warfare in numerical terms. With odds of making it safely through one mission realistically estimated to be 50%, only 1 out of 1000 fighter aircraft could be expected to survive more than 10 missions \([1:2^{10}]\). These pilots are depending on a myriad of electronic measures and countermeasures to get to their target, release their 20 seconds worth of ammunition, and return safely. Although the numbers are different, today's helicopter gunship faces similar challenges with various guided anti-tank weapons.

The modern battlefield has undergone significant evolution during the last two decades. Weapons have greater ranges, causing them to be more weather dependent in terms of air clarity and fog. Night vision devices are allowing better vision at night, making the nighttime weather a factor. Microwave and radio wave communications require line-of-sight intervisibility over great distances.

In order to write tactical doctrine which will be effective in the future, the U.S. Army has begun to explore the nature of the next perceived war. While the following quotation was intended to describe a future battlefield, it goes a long way towards describing a battle which is within the electronic warfare technology of today:

"We should expect the battlefield of the 21st Century to be dense with sophisticated combat systems whose ranges, lethality, and employment capabilities surpass anything known in contemporary warfare. The airspace over the battlefield will be saturated with aerial and space surveillance, reconnaissance, and target acquisition systems. Air defense weapons will exist
to deny the use of these aerial platforms. The conflict will be intense and devastating, particularly at any point of decisive battle, thus making it extremely difficult to determine the exact situation. In such an atmosphere of confusion, command and control will be exceedingly difficult. It appears that no single weapon system can be fielded to cope with the total battle requirements. The battle will be waged with integrated systems of all arms and services. Battlefield mobility will be an absolute essential for success. One other aspect of the future battle is drawn from the growing proliferation of nuclear, chemical, and biological weapons, coupled with the enemy's apparent permissive attitude regarding employment of these weapons. It is imperative that forces plan from the outset to fight dispersed on this 'conventional-nuclear-chemical-biological-electronic battlefield'.

(U.S. Army, 1982b)

In summary, the electronic battlefield thus described is going to give a decided advantage to the side which has a rapid response terrain analysis capability. The battle will move fast. With each new changing situation, timely terrain intelligence products which are able to meet the tactical commander's demands, will make the difference in who wins the battles and ultimately the war. Additionally, a key element of any terrain analysis system in the future will be the capability to quickly analyze lines of sight over large distances and display areas which are masked from line-of-sight intervisibility from a given observation point.
CHAPTER 4
PRESENT STATUS OF TERRAIN ANALYSIS AND FUTURE INITIATIVES

The Army Terrain Analysis System of the 80's

In addition to the increasing terrain information demands derived from electronic warfare, the Falklands war in 1982 and the Granada invasion in 1983 both served to validate the importance of quick response terrain information. While the British Task Force was sailing south to the Falkland Islands, terrain information was being processed and disseminated to the commanders; in the case of Granada, maps and terrain information were quickly assembled on a 24 hour notice. These examples best illustrate the trade-off considerations between quality and speed. This author saw some of the geographic information products produced for the Granada invasion. Although they were simple and in some cases the sources were nothing more than tourist brochures, the information was produced on time, and was better than no information at all. Even the best terrain intelligence is of no use if it can't be processed and put in the user's hands before the war is over. On the other hand, quick response terrain intelligence is useless if it is unreadable or if it consists of information which does not meet the needs of the military commander. Terrain intelligence must be both accurate and responsive. Furthermore, the term responsive suggests that it is both timely and that it meets the user's specific needs.

At present, the terrain analysis system in use in the U.S. Army is a manual system. As such, it is painfully slow when compared to the computer based geographic information systems in use today. However, response time is not the complete picture; albeit slow, the manual system is accurate and responsive to user's demands. In addition, other factors such as data base analysis costs, hardware costs, budget priorities, or the need for human involvement in the synthesis process may also be pertinent. In order to provide a better background to the discussion of future directions, the present manual terrain analysis system will be examined first in more detail; this will be followed by a discussion of the implications of the MICROFIX
microcomputer system which has already been fielded into Army units; next, a more advanced microcomputer system (TOPOFIX), tailored to topographic needs, will be discussed; finally, a future computer-based terrain analysis system known as Digital Topographic Support System (DTSS) will be briefly examined.

With the manual terrain analysis system, the synthesis of a terrain product begins with a specific request from a military commander. The terrain analyst pulls the appropriate thematic overlays and other data from his data storage files, synthesizes the required information by stacking the overlays and manipulating the associated data, and manually traces out the finished product. Aerial photographs may be consulted if available. This system contains great flexibility in that the special product can be tailored to the exact needs and specifications of the user. An overhead concealment product could be produced for any season of the year using knowledge of the deciduous nature of the trees. A cross-country movement (CCM) graphic could be made for wet or dry conditions; for wheeled or tracked vehicles and so on.

Two examples of the manual synthesis of a terrain product are shown in figure 6. These are rather simplistic models of actual terrain products, especially the overhead concealment example in figure 6a. In reality the thematic overlays in the data base are more complex than those shown. In the case of cross-country movement (CCM) such as in the example in figure 6b, the synthesis of a terrain product can get quite complicated with up to 500 complex factor areas required in the speed prediction tabulation. A programmable calculator or microcomputer could be quite useful here in calculating the predicted speed even without digital data. The computer algorithm could store and manipulate the various slowdown factors; however, since the data are not digital, it cannot be addressed directly. The terrain analyst would still have to manually enter the vegetation, slope, and soil types for each of the 500 complex factor areas. A typical overhead concealment product could be produced within one or two man-hours. A CCM product could take considerably longer--up to 30 man-hours depending on the complexity of the area, and no less than 5 or 6 hours regardless of how many people worked on it. These figures are derived from the author's experience in a Topographic Battalion, and

![Diagram showing synthesis of Overhead concealment from vegetation overlay in data base.]

- **Data Base**:
  - A1: dry crop agriculture
  - C24: 25-50% canopy closure, 10-15 meter heights
  - C45: evergreen forest
  - D14: < 25% canopy closure, 10-15 meter heights

- **Synthesis**:
  1. Evergreen canopy closure: 75-100%
  2. Evergreen canopy closure: 25-50%

- **Product** (overprinted with Concealment areas)
  - Excellent
  - Fair
  - Poor

![Overhead Concealment (Winter) map]

b. Synthesis of Cross Country Movement for some imaginary tracked vehicle. This example only applies to the wet season. The factors for soils would likely be less severe in dry weather.

![Diagram showing synthesis of Cross Country Movement for some imaginary tracked vehicle.]

- **Complex Factor Areas**
  - Various slowdown factors multiplied
  - Speed Prediction
  - Veg | Slope | Soils | factor kph
  - 1 | 1.0 x 1.3 x 2.0 = 2.6 | 10-15
  - 2 | 1.0 x 1.3 x 1.1 = 1.43 > 15
  - 3 | 1.1 x 1.3 x 1.1 = 1.57 > 15
  - 9 | 3.0 x 1.7 x 1.3 = 6.63 No Go

![Cross-Country Movement Map]

**Figure 6.** Several examples of the synthesis of terrain products from the hard copy mylar Tactical Terrain Analysis Data Base (TTADB). The speed prediction tabulation in the latter example could become quite complex if the number of complex factor areas was increased to a more realistic 400 or 500 polygons.
are based on the expertise of experienced terrain analysts. The "design" response time with the outdated TSS equipment is still 48 hours including multiple press copies.

The data output for this manual terrain analysis system can take several different forms. One user may only require a pencil sketch or overlay in one copy. However, if the situation requires more than several copies, then another 4 or 5 hours would be required to make a plate and set up the press (2000 copies per hour). If an eleven hour wait is fast enough for the military commander who requested the product then this system works fine. This may be acceptable for planning before the battle starts; but once the clash begins, the need for new and unforeseen terrain products will rise geometrically, and faster response times will be required.

More recently, large format electrostatic photocopiers have been used to produce multiple copies in black and white in a matter of minutes instead of hours. This eliminates the reproduction time but does not speed up the analysis. An additional disadvantage of the manual terrain system is the relative bulk and awkwardness of the data base format. Terrain information (soils, vegetation, slopes etc.) are presented on map size stable base film positives and mylar overlays. The data base for a Division area is perhaps manageable in a van full of flat file map cabinets; however, the data base at 1:50,000 of a Corps area of responsibility becomes quite cumbersome.

This terrain analysis system does work, albeit somewhat slow to respond and bulky to store. However, slow and bulky is better than nothing at all. The advantages of this system are the accuracy of its data base, its flexibility in the final product format, and its responsiveness to user defined needs. In addition, in a defensive situation such as the U.S. finds itself in Korea and the NATO defense of Europe, the need for a rapid response time is mollified by the need for advance defense planning and war gaming over known terrain. Terrain studies and CCM products can be produced for likely battlefields well in advance.

The aforementioned advantages of the present Army terrain analysis system have arisen in part from the organizational structure the Army has chosen to utilize. In contrast to the geographers of World War II who conducted studies in Washington D.C. to aid in the strategic
planning at the Pentagon, today's terrain analyst belongs to a Terrain Team at the Theater Army, Corps, and Division level. At this level, terrain information is both more accessible and more responsive to the tactical needs of commanders of Divisions, Brigades, Battalions and Companies. Much of the quality and flexibility of terrain products depends on the subjective understanding and decisions of the personnel on the terrain team. The Theater and Corps Teams have about twenty members and the Division Teams have five. These personnel must understand the commanders needs and must be able to communicate the terrain conditions to the battlefield user's in understandable graphics and language. This is accomplished by training each of the terrain analysts in a designated Military Occupational Specialty (MOS) called Terrain Analyst. Perhaps even more important in this process is the Warrant Officer in charge of these teams who provides the technical management and supervision of the analysis and synthesis process. These personnel are trained at DMA's Defense Mapping School and it is done by military personnel with backgrounds in geography and related systematic sciences.

In short, the primary advantages of the present Army terrain analysis system are its flexibility, responsiveness to user's needs, and its ability to produce accurate meaningful terrain intelligence. The primary disadvantages are its slow response time (relative to wartime response needs), and to a lesser degree, the cumbersome nature of its database overlays.

The First Step Towards Digital Data: MICROFIX

Getting a new defense technology or system through the maze of research and development, testing, funding, contracting, and procurement can be described as nightmarish, at best. Thus, even the most optimistic development cycles for non-weapon systems can take five years or longer. Recognizing this constraint, as well as the very strong need to obtain computer assistance as soon as possible, the Intelligence and Engineer branches of the U.S. Army cooperated in the the procurement of an interim solution, known as MICROFIX (an acronym meaning: a "MICRO" computer being used to "FIX" an information storage problem). This involved the purchase and fielding of Apple II microcomputers with a 20 mb
hard disk and a video disk player. This was originally conceived of as an expedient method of data storage, data retrieval, file management, and report generation. These hardware items were purchased off-the-shelf and modified slightly in respect to their outer cases and electronic shielding in order to make them usable in a classified environment. MICROFIX, with its associated software, is capable of storing vast amount of information in user defined formats, which is at the same time integrated with geographic locations on the color display of video disk maps. The information can be displayed as an overlay on the color map on the monitor screen, or printed out in hard copy report formats.

Although primarily intended for data base management for Army Intelligence units, the MICROFIX system has found a welcome home with the Army's terrain analysts. Although it does not replace the manual terrain system, with its manual hard copy terrain data base, it does provide for the management, storage and retrieval of the vast amounts of collateral data which accompanies the data base overlays. Some of the data base categories already defined are bridges, airfields, river crossings, tunnels, route constrictions, obstacles and water supplies. Several other useful software packages have been included which assist the terrain analyst in doing his job. The Battlefield Environmental Effects Software (BEES) is a series of programs designed to aid military operation planning by determining the environmental effects on personnel and equipment. It includes such functions as density altitude computations for helicopter load determinations, sunrise/sunset and moonrise/moonset time calculation, historical climatic data, and paradrop climatology. Also included are utility programs such as a relational data base, a word processor, and a spreadsheet.

One other program being added to MICROFIX is a small line-of-sight and area masking program. Dealing with the area of 1/4 map sheet at 1:50,000, it can draw profiles and line of sight cross-sections from user defined reference points. Perhaps more important, is its ability to draw area making maps with consideration given to vegetation and built-up area heights.

While MICROFIX has filled a critical gap in the Army's terrain analysis program, it is not in any sense of the word a digital terrain analysis system. The digital data stored by
MICROFIX contain only the feature information regarding specific locations. It does not have the capacity to store the vast amounts of digital areal data required for a full geographic information system. It has increased the terrain team's ability to do some analysis with BEES and the line-of-sight programs; however, the vast majority of terrain analysis must still be accomplished by the manual methods already described. In short, MICROFIX can be welcomed as a very useful and beneficial tool. Nevertheless, terrain analysis will, for the most part, be too slow in response during the next war.

A Step Further: TOPOFIX

The limitations of the MICROFIX system were recognized from the beginning. Now after three years in the field, the lessons and experience from this interim solution are being implemented into another interim “fix” pending the arrival of DTSS. The Computer Graphics Laboratory (CGL) of the Department of Geography and Computer Science at the U.S. Military Academy, in conjunction with the Belvoir Research and Development Center (BRDC), are presently fielding a new test configuration of a computer-assisted terrain analysis package called, TOPOFIX. The Development Plan for TOPOFIX (USMA, 1986) states the purpose of this system: "...to apply the lessons learned from MICROFIX...to a more compact and responsive package. The focus is the enhancement of the present level of automation of the Topographic Terrain Teams within the Military Geographic Information subsystem of the Topographic Support System (TSS), and to gain practical experience in the automation of topographic support".

This TOPOFIX system consists of: a compact portable microcomputer with an 80286 processing chip, a numeric co-processor, 4 MB RAM, 20 MB removable hard disk drive, 2400 bps modem, and MS-DOS 3.0 operating system; a color monitor; a digitizer; a plotter; a 1/2 inch tape drive; and a printer. The main additional features over the MICROFIX are the large increase in memory and storage, and the addition of a digitizer and plotter. In going with a different operating system, the developers felt the need to break away from the Apple II
architecture because of the limitations of its processing speed as well as its lack of portability. CGL has already developed software for downloading and utilizing DMA digital data, which can then be utilized by MS-DOS compatible machines (USMA, 1986). Additionally, the use of MS-DOS will allow the developers to utilize some potentially useful commercial software.

The Next Step: Digital Topographic Support System (DTSS)

The value of digital terrain data is not a new concept to military scientists. In 1972, Army Field Manual 30-10 stated that an automated system for storage and dissemination of military geographic information "is presently being developed" (U.S. Army, 1972). The authors of this manual foresaw taking vast arrays of geographic data, digitizing them, and incorporating them into an automated system with standardized data format. Indeed, a showcase computer system, known as the Terrain Analysis Work Station (TAWS) has been around for some time at ETL. TAWS is a system of computer assisted techniques for extracting, interpreting and displaying terrain information. It utilizes true digital data and has the capabilities of a full geographic information system. However, the step from such a laboratory demonstrator to a working system in the field is a giant one. The final system envisioned by researchers at ETL is a geographic information workstation called Digital Topographic Support System (DTSS).

As its name implies, the DTSS will rely primarily on digital data. Its main components will include a minicomputer, a digitizing workstation with monitor, some form of mass magnetic storage, and an output plotter device. These are really the same basic components contained in MICROFIX and TOPOFIX, with the exception that DTSS will be much more powerful and the final production hardware will meet whatever specifications that have been generated by the development cycle. In essence, TAWS is a collection of off-the-shelf hardware items which are designed as a test-bed for software and hardware ultimately intended for DTSS. MICROFIX and TOPOFIX, while bearing some resemblance to a scaled down model of DTSS, are actually outside of this development cycle. The key differences are that
MICROFIX is presently in user's hands, TOPOFIX is being tested for possible fielding with Terrain Teams, TAWS is sitting in a development laboratory as a demonstrator, and DTSS does not yet exist. To put it another way, MICROFIX is coming to the end of its useful life as an interim "fix", TOPOFIX is waiting in the wings as a further interim "fix", and TAWS is doing its best to validate the future needs for DTSS.

The key features which really set DTSS apart from the improved capabilities of TOPOFIX and the present manual system, are its great speed, flexibility, and ease of use with large digital data bases. With DTSS the analyst could query the computer for information in a manner such as: a) display as "No Go" all areas that have tree stem spacing less than a and stem diameter greater than b, or have slope categories d or e, or have soils in category f or g, or have some combination of stem spacing h, stem diameter i, and slope j; b) display as "Slow Go" all areas that have some combination of tree characteristic, slope and soils; c) display all other areas as "Go"; d) display all contents of obstacle file. In a manner of minutes the analyst would have the product displayed on a screen at which time he could then edit, change criteria, add text or otherwise manipulate the output. Furthermore, the principal reasons for each "no go" areas could be overprinted or listed as a separate document. The finished CCM product could be printed and ready for the customer minutes after the request was received, and the customer could actually change his mind on product specifications without much trouble. This flexibility is one of the greatest advantages to a system with a digital data base. Military commanders would not be limited to certain "standard" products; the only limitation would be one's imagination. Furthermore, the digital nature of the data base and its overlay products would also allow for the electronic transmission of the output.

The digital data base for DTSS needs to be discussed. In the interim period before DTSS is fielded, DMA's terrain analysts are continuing to produce the hard copy mylar terrain data bases for the Army's Terrain Teams. When DTSS is implemented, it is apparent that these overlays will become obsolete. That possibility is not as serious as it sounds. It makes sense to have a manual hard copy data base as a back-up system for the future eventuality of
computer or electric power failure. A more serious concern is the very real possibility that the DTSS system will be fielded without any digital data to analyze. This concern is partially mitigated by the present existence of DMA's Digital Terrain Elevation Data, Level 1 (DTED-1) and Digital Feature Analysis Data, Level 1 (DFAD-1). These data are available for a significant portion of the northern hemisphere in the case of the elevation data and significantly less for the feature data (DMA, 1983). However, the data are not adequate for tactical terrain analysis due to their lack of detail. They would be excellent for small scale area masking studies but would not provide the detail of slopes needed to determine cross-country mobility. It is interesting to compare the analysis time for a 1:50,000 masked area plot using manual methods versus the DTSS prototype, TAWS. Such an overlay would identify all terrain which was masked from intervisibility from a referenced point on the map. It was estimated that it would take an experienced terrain analyst about 50 hours with a hand calculator; the same was accomplished by TAWS in 2 1/2 minutes (data from Major Quick, ETL).

Other levels of data are being produced, but the coverage is not very extensive as yet. Historically, the DTED-1 data were first produced in 1972 to meet the radar training simulation needs of the U.S. Air Force. Later, requests for digital data began to come from all the armed services and the specifications were modified in an effort to include all users. In 1981, DMA was asked to explore the expansion of their digital data to include the terrain analysis elements of the standard 1:50,000 tactical terrain data base (Pierce, 1982). However, only several prototypes were produced; the decision on full scale production is forthcoming.
CHAPTER 5
FUTURE DIRECTION FOR TERRAIN ANALYSIS

Discussion

Having looked at the historical development of terrain analysis, as well as the present capabilities and research initiatives, it is now time to discuss the questions posed in the introduction to this paper in relation to DTSS. Are the new information and terrain analysis systems being driven by technology itself or by real and historically valid needs? It seems evident that the need for faster and more flexible terrain intelligence is valid. Over the years the terrain itself has remained relatively constant. A river is still a river, a slope is still a slope, a soil is still a soil. However, man's utilization of the terrain has expanded into new dimensions—witness the airplane, rocket, and harnessing of electromagnetic radiation. This has resulted in new terrain dependences and a greater need for extremely rapid response terrain products. In order to win the battle, a commander must see the battlefield with all its terrain implications and be able to react quickly to rapidly changing tactical situations.

In the long term, are important gaps being left in terrain analysis capabilities within the defense establishment? Just ten years ago the answer to that question would have been a clear yes. Today, there are still gaps, but they are closing fast. Terrain analysis doctrines, organization, and capabilities were slow to develop during the last quarter century. The technological revolution began to produce weapons, weapons platforms, vehicles, and electronic devices in quick succession. Fortunately, there was a corresponding development of information storage/retrieval and computer analysis technology. Furthermore, the Army has not sat around wringing its hands waiting for the cumbersome procurement cycle to place an all-inclusive technological solution in their laps in the 1990's (DTSS). Instead, they have gone ahead with near term "fixes" to the problem which have been able to do more than just treat the symptoms. MICROFIX and TOPOFIX are at once providing an expanded interim analysis and storage capability as well as providing an opportunity to test future requirements and
capabilities.

However, there appears to be an important shortcoming in future terrain analysis capabilities. The digital data base is incomplete except for a few demonstration areas such as Ft. Lewis. While TAWS can parade around effectively demonstrating the future capabilities of DTSS, an important caveat must be added: the terrain analysis digital data base is inadequate for perceived future needs. Granted, DMA's digital elevation and feature data are extensive; however, a good terrain data base needs vegetation, soils, transportation, hydrology, and obstacle information. Furthermore, the DMA's elevation data are not dense enough to provide slope information at the large scales required by terrain analysts.

Is it reasonable and feasible to expect computer systems to replace, in some measure, what has historically been accomplished through manual terrain analysis? It is obvious that computers have the advantage in terms of data storage and speed of information retrieval and processing. But can a computer replace the personnel on these five and twenty member terrain teams? No. The historical perspective is enlightening. The use of terrain analysis in WWI was limited to some applied geology and the descriptions of the key terrain after the war was over. It was basically up to the "terrain sense" of each individual commander to utilize terrain intelligence in tactical planning. Perhaps "terrain intuition" is an applicable term. There is an intangible thought process which cannot as yet be programmed into a computer. The commander who decided to dig a tunnel under the enemy hill in order to blow it up and take the high ground, did not need a computer to give him advice. Even if a computer had been available it probably wouldn't have helped. This commander sought expert opinion from the geologists on his staff. WWII saw every available geographer pressed into government service to solve military problems never faced before. These interdisciplinary teams were successful in solving a myriad of topical and regional military geographical issues. If today's computers had been available to these WWII geographers would they have been useful? Yes. Would a computer have produced the high quality JANIS terrain studies referred to earlier? No. Only professional human intelligence, using geographical methods could have put together the
relevant facts in such a short time into a meaningful terrain study.

One of the most helpful characteristics found in a good terrain analyst, is good old common sense. A terrain analyst must have common sense. This author has spent several years teaching terrain analysis; it was found that the skills of effectively analyzing terrain could not be taught to someone who lacked common sense. Computers cannot, as yet, be programmed to utilize common sense. The computer can be an infallible reasoning machine, but it doesn’t have the intuitive, gut feelings that play such an important role in the decision making process. A terrain product produced by a computer consists of a series of binary decisions based on the data. Although the program could be designed to produce a series of “if this, then that” options, this is not the same as common sense. The key word is assist. Computers can assist in producing terrain intelligence, but it takes human intelligence to interpret the results or incorporate relevant facts that may not be in the data base. Subjective decisions will not go away with computer assisted analysis. The so-called “expert systems” being developed for such fields as medical and automotive diagnosis are effective only because the diagnosis can be reduced and programmed into a finite number of rules.

War in the future will be no different than past wars in some respects: one should expect the unexpected. If anything can go wrong, it will. All the pre-war planning and data collection can be lost with just one unpredictable event. Because of this, the human part of the terrain analysis process becomes very important. Manual terrain analysis may be the key to battle success if the computer has been damaged or power cut off.

Digitizing Options

The lack of a standardized digital data base for terrain analysis has been identified as a major future shortcoming of DTSS. It makes good sense to begin the digitizing process now in order to be ready when DTSS is funded and fielded. Moreover, it would not hurt to have digital data available for use in the interim TOPOFIX. There are several approaches toward digitizing which could be taken. One could digitize the terrain data in the collection phase
Digitizing during the collection phase would be simplified if multispectral scanner data such as produced by Landsat could be utilized. However, the scale of the image is too small to be of significant use to the terrain analyst. Because each pixel is approximately 79 by 57 meters (=1.1 acres) on the ground, the most detail that could be obtained would be the average spectral data for each acre. In short, the pattern and terrain information available on Landsat is too coarse. Vogel (1977) and Rodrique and Thompson (1982) all concluded that Landsat data are inadequate for military terrain analysis. Nevertheless, ETL is continuing with research into the future use of multispectral data. Initial results from studies with NASA's new high resolution Thematic Mapper has shown promise. ETL plans to expand its investigation of the use of high resolution multispectral data (U.S. Army, 1985).

If the scale of the satellite multispectral scanners is too small, couldn't one digitally collect or otherwise digitize the larger scale photography the present terrain analysts manually interpret? The answer is a qualified yes. At present it is not very practical. The U.S. Army (1979) describes scanning microdensitometers or video systems as very effective means to create numerical records of photographs. But the problems of spatial registration with a map base are significant. In order to have a consistent base reference such as the UTM grid, one either has to rectify the photography before it is analyzed or somehow rectify the completed analysis overlays. Although the automated rectification of photos as practiced by the U.S. Geological Survey and Defense Mapping Agency is quite advanced, this roundabout approach does not appear to be practical. Furthermore, some terrain patterns are not adapted to accurate interpretation by automated methods even if larger scale imagery was used. Brink, Patridge, and Williams (1982) noted that "computer mapping from spectral imagery by means of signature matching has shown some promise in mapping land use and vegetation in local areas, but has not been very successful in mapping soil types, for which there is, as yet, no substitute for human interpretation". The use of higher-resolution multispectral digital data needs further
research. Rodrique and Thompson (1982) describe tests done with data collected in five bands (blue, green, red, infrared, and thermal infrared) and a pixel size corresponding to 12 feet on the ground. This sounds promising for a digital data base. However, "... it was revealed that a spectral classifier alone could not accurately classify the terrain, even with high resolution data, because seemingly homogeneous features were often statistically nonhomogeneous". Thus, it appears that digitizing at the data collection phase is not feasible at present.

Perhaps the terrain data could be digitized subsequent to the data collection. It is suggested that the thematic overlays, which already exist for many parts of the world in flat files, could be digitized as an additional step in their manual production. The overlays are a series of polygons (as depicted earlier in figure 6) and are already registered to base maps. A vector digitizing board could be used to trace around all the polygon boundaries and the associated characteristics of each map unit could be assigned in the computer file. Junkin (1981) has described how this was successfully done for a soil map. He digitized about 1/8 of this map in three hours. This translates into about 24 manhours for a full sheet. At first this appears to be a great deal of effort. However, if the thematic overlays are now being produced manually by an analyst delineating areas on a sheet of mylar, it seems logical for the same analyst to go one step further and digitize his lines at the same time. Once he has a draft completed he could digitize it in about the same time it would take him to ink his final "camera ready" copy. In this manner digitized thematic overlays could be produced with little effort beyond the manual construction. The resulting data base would lend itself to the processing and computer merging of various overlays. Thompson and Socher (1982) describe how a complete set of thematic overlays keyed to a 1:50,000 map sheet in West Germany were digitized and integrated into a geographic information system called the Digital Terrain Analysis Station (DTAS). This polygon based system was able to successfully produce many synthesized products using standard boolean operations.

Similarly, the thematic overlays could be digitized by a scanning densitometer. The Remote Sensing Applications Guide (U.S. Army, 1979) describes how this digital record
could be run through a program which identifies each area which has been surrounded by a polygon. The program then labels each pixel within that area with the appropriate attribute. This puts the data in a format which can be easily stacked and the various attributes of each corresponding pixel in each layer could be registered to each other (figure 7a). An alternate approach would be to take the vector maps from the previous paragraph and do a raster transformation of the data as shown in figure 7b.

In summary, three approaches have been described by which the present terrain thematic overlays could be digitized: 1) vector digitizing of polygons; 2) vector digitizing of polygons with subsequent raster transformation; and 3) the raster digitizing of polygons by densitometer. This decision would primarily be based on the type of data that the DTSS software was designed to utilize, as well as the time and cost factors of each process.
a. Example of the synthesis of 4 digital terrain overlays. A computer allows the rapid synthesis of millions of such factor codes from two or more stacked overlays. The speed of this process allows the analyst to experiment with several different "what if" options in the analysis process.

b. The present hard copy terrain data base could be digitized by scanning with a densitometer and by subsequent raster transformation of the vector polygons.

**Figure 7.** Graphic portrayals of raster digitized areal data and the transformation of vector polygons into the raster mode (figure 7b is after Junkin, 1983).
CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The focus of this paper has been on the historical setting through which military geography and terrain analysis have developed. As the discipline of geography became established it was natural for military applications to surface. The German geographers were particularly active in the early military applications of geography. The military conflicts during the 1900's pushed military geography towards maturity; consequently, its growth was centered around these wars and was relatively slow over the long term. The application of military geography during World War I could be likened to the concept of "management by crisis". Rail and wheeled vehicle mobility, new fighting concepts such as trench warfare, and the introduction of tanks and machine guns forced military planners and commanders to rush to geographers with a plea for help. In the United States, geographers were commissioned to study the war and military geography was taught at universities and military schools.

World War II likewise demonstrated rapid growth in military geography. Aerial photography was utilized effectively as a collection tool and geographic considerations became a part of tactical planning. This war launched the United States as a world power, making military geography an integral part of the U. S. Defense establishment. The terrain analysis production of this period was planned and accomplished at the Department of Defense staff level.

Further conflicts in the 50's and 60's helped to formulate the Army's terrain analysis doctrine into the concept of terrain intelligence as a multiplier of combat power. Military laboratories, established since World War II, became actively involved in the quantitative aspects of military geography. When it was realized that terrain factors could be modeled and predicted with reasonable accuracy, the present Army terrain analysis program was born. These concepts evolved through the 1970's until in the 80's the Army's terrain analysis was
organized into efficient units which were close to their principal customers--namely the tactical commanders. The terrain intelligence which is produced by these Terrain Teams is flexible and responsive to users' needs. However, it suffers from one major flaw--it is too slow.

The battlefield of tomorrow will be fast, fluid, and lethal. Army terrain analysis must likewise be both fast and flexible and must be able to have manual backup capabilities. Computer assisted terrain analysis within the present terrain team structure will be the key to meeting these needs. MICROFIX has demonstrated how vital this computer assistance can be. TOPOFIX will go even further in this regard. Finally, DTSS will be fielded to terrain teams who are already computer literate and understand the manipulation of digital data. However, DTSS will be no better than MICROFIX or TOPOFIX unless steps are taken now to produce the digital terrain data required to make the computer more than just a "tank without ammunition".

**Recommendations**

1. Keep the present level of manning in the Army Terrain Teams. The human element in the terrain analysis process has been validated historically. Computers cannot replace the common sense approach of a well trained terrain analysis team. Computer algorithms cannot accomplish the many subjective decisions and explanations required in most terrain analyses. The exceptions to the "rules" that are not contained in the data base could spell disaster on the battlefield without the human intelligence to modify or qualify the synthesized results. In addition, the personnel are required in order to accomplish manual terrain analysis with the old manual data base, when (not if) the computer fails.

2. While computers may not replace human analysis in the near term, they have demonstrated their potential to assist. The recommendation for human input into the analysis process does not preclude the search for more effective tools. As such, further research into artificial intelligence and expert systems should be pursued with terrain analysis applications in mind. Any effort which has the potential to amplify the present computer assistance in the
terrain analysis process should proved cost effective in the long term.

3. The Army's "something is better than nothing" approach with MICROFIX and TOPOFIX is on the right track. These terrain analysts, who are true military geographers, need all the assistance they can get in storing, retrieving, analyzing, and synthesizing vast amounts of geographical data. In today's potential battlefield, response time carries equal weight with information accuracy. As such, TOPOFIX should be developed with the view to placing one in each Terrain Team.

4. The Army needs to take immediate steps towards a standardized digital data base. It may be possible to digitize the present manual thematic overlays for very little additional cost. Further research is required to determine the most cost effective method for accomplishing this digitizing.
### Appendix A

**Systematic and Topical Military Geography Categories**  
*(listed by Peltier, 1962)*

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<td>Q. Urban Warfare and Civil Defense</td>
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Appendix B

Literature Cited


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B- 2