Carbonate rocks and American Civil War infantry tactics

Scott P. Hippensteel
Department of Geography and Earth Sciences, University of North Carolina at Charlotte, 9201 University City Boulevard, Charlotte, North Carolina 28223, USA

ABSTRACT

The most studied battleground from the American Civil War, from a geological perspective, is the rolling terrain surrounding Gettysburg, Pennsylvania. Here, the mixture of harder diabase and softer sedimentary rocks produced famous geomorphic features such as Cemetery Hill and Little Round Top that provided strong defensive positions for the Union Army. Another even more common type of rock—carbonates—provided similarly formidable defensive positions at numerous other battlefields in both the eastern and western theaters of conflict. Limestones and dolostones shaped the terrain of multiple important battle sites, including Antietam, Stones River, Chickamauga, Franklin, Nashville, and Monocacy, and these rock types proved consequential with respect to the tactics employed by both Union and Confederate commanders.

On many battlefields, outcropping limestone proved beneficial for attacking troops; differential weathering within carbonate formations produced rolling terrain that limited the range and effectiveness of both artillery and small arms (e.g., “Sunken Road” at Antietam). Thin regoliths above limestone also prevented tillage, and the resulting forests provided concealment and cover for advancing troops (e.g., Stones River). From a defensive perspective, on a larger geographic scale, carbonates provided natural high ground from chert-enriched limestones and dolostones (e.g., Missionary Ridge, Chickamauga, Franklin, and Nashville). On a smaller scale, erosion of these same rocks produced karrens that provided natural rock-lined trenches for defending troops (e.g., “Slaughter Pen” at Stones River).

Analysis of casualty figures (killed and wounded only) indicates similar losses (~15% of troops engaged) whether soldiers were attacking across carbonate rock, non-carbonate rock, or unconsolidated sediments. Soldiers defending ground underlain by limestones and dolostones had a slightly higher casualty rate (14%) than those defending terrain above non-carbonate rocks or unconsolidated sediments (12%). This suggests, in a limited manner, that the local smaller-scale defensive advantages provided by limestone, such as karrens, were not as important as the regional-scale advantages for attacking troops, including rolling terrain or forest cover.

INTRODUCTION

Much of the earlier research that investigated geology and the American Civil War focused on the regional influences of structural settings and resulting geomorphology and how these large-scale landscape features dictated troop movement and concentration (e.g., Zen and Walker, 2000). This article deals with the smaller-scale relationship between local battlefield geology and the tactics and strategies utilized by commanders on both sides of the conflict.

The most observable and studied relationship between Civil War combat tactics and strategy and geology occurred on the battleground surrounding Gettysburg, Pennsylvania. All three days of fighting witnessed Union delaying actions and defensive resistance centered upon imposing geological landscape features. Here ridges composed of Jurassic diabase and sloping lowlands composed of Triassic sandstone and shale dictated the terrain most suitable for defense. At numerous other critical battle sites, however, it was carbonate rock, and its weathering characteristics, that played a significant role in the success or failure of defensive positions.

Carbonate geology aided both Union and Confederate forces in holding key defensive positions during a number of important battles throughout the war in both the eastern and western theaters of conflict. Whether erosion-resistant ridges provided high ground, bedrock fractures provided natural trenches, or eroded limestone boulders created material for breastworks, the geology of the field could be used by commanders to establish stronger defensive lines. Conversely, carbonate rocks and weathering often provided benefits for attacking troops by providing visibility cover in the form of rolling terrain or forests (cultivation for agriculture was impossible due to the limestone in the shallow subsurface). The changing combat environment (i.e., increased range of the rifled musket compared with earlier smoothbore weapons) enhanced the defensive superiority provided by the rocks. This article discusses the role of carbonate rocks and weathering on multiple major battles from the eastern and western campaigns of the Civil War.

PREVIOUS STUDIES OF GEOLOGY AND DEFENSIVE TACTICS: GETTYSBURG, PENNSYLVANIA

During the three days of battle in early July 1863, the Union Army repeatedly occupied the high ground created by differential weathering rates of the York Haven Diabase and Rossville Diabase sills and dikes and the more erosion-prone mudstones and shales of the Triassic Gettysburg Formation. The durable outcropping diabase proved especially important for the Union defensive positions. All of the famous defensive terrain features, including Seminary Ridge, Little Round Top, Culp’s Hill, and Cemetery Ridge, are underlain by this rock, and during the repeated assaults on July 2 and 3, the diabase outcrop feature known as Devil’s Den was the only region of the field successfully attacked...
by Confederate forces. On the third and climactic day of the battle, Confederate General R.E. Lee ordered what has colloquially been known as “Pickett’s Charge.” This attack involved 12,500 troops moving from Seminary Ridge underlain by the Jurassic Rossville Diabase, across more than a kilometer of open ground underlain by the claystone, mudstone, shale, siltstone, and fine sandstone of the Triassic Gettysburg Formation, before reaching the Union infantry defending Cemetery Ridge underlain by the Jurassic York Haven Diabase.

Little doubt can remain as to why Gettysburg is the most studied battle in American history and the most studied battleground from a geologic perspective (e.g., Brown, 1962; Inners et al., 2004, 2006; Smith and Keen, 2004; Neubaum, 2013). These studies documented the role of geology in influencing critical aspects of Civil War tactics, including dictating the positions of defensive lines on natural ridges, the availability of boulders for defensive cover or the building of stone walls, the availability of groundwater, and how the shallow depth of bedrock might prohibit sappers from digging trenches. What has not been as thoroughly investigated, however, is how all of these factors were also a determinant at other Civil War battle sites—not because of diabase and sandstone, but because of the underlying limestone and dolostone.

Four critical battles—Antietam, Stones River, Chickamauga, and Monocacy—were chosen as case studies in which carbonate rocks and outcrops are discussed in detail. The battles are discussed in chronological order, switching between the two campaigns (Fig. 1). Two themes emerge when considering these battles from a geologic perspective: (1) armies on both sides found defending lines anchored on “enriched” (weathering-resistant) limestone especially effective at providing defensive cover, and this effect was magnified if the opposing forces were attacking across lower gradient terrain underlain by softer, more erodible limestone; and (2) differential rates of weathering of limestone often produced exceptionally strong defensive positions and, in some cases, natural trenches composed of rock.

CRITICAL DEFENSIVE POSITIONS AND CARBONATE GEOLOGY: FOUR CASE STUDIES

Antietam (Sharpsburg), Maryland

The battle around Antietam Creek, Maryland, occurred on September 17, 1862, during Confederate General Robert E. Lee’s initial attempt to bring the war onto northern soil. This single day of fighting witnessed a series of disjointed attacks by Union General George McClellan’s much larger force against that of the Confederate Army of Northern Virginia. The results of the battle were a tactical—and bloody—stalemate. Nevertheless, the battle was considered a strategic victory by the North, as the Confederate Army retreated into northern Virginia.

Antietam Battlefield is underlain by three carbonate units that provide different terrain features that were exploited by the Confederate Army on defense during multiple phases of the battle. The northwestern third of the battleground is underlain by the Conococheague Limestone. This Cambrian–Ordovician unit is composed of dark blue, laminated, oolitic, argillaceous, and siliceous limestones, which are thinly bedded with siliceous partings that tend to weather out in relief (Fig. 2) (Cleaves et al., 1968). The Conococheague Formation trends north-northwest, and the relatively pure consistency of the limestone produces open terrain with little change in relief (Ehlen and Whisonant, 2008). This type of karst topography typically has little surface drainage (stream valleys) to provide cover for advancing troops, and long-range visibility is greater; the result is a decrease in concealment for troop movement and an increase in the effectiveness of artillery at range.

The middle portion of the battlefield, which includes the (in)famous sunken road, is underlain by the Elbrook Formation, which consists of a mixture of dolostone, limestone, and some shale beds (Fig. 3). This thick series of shale-y limestones and calcareous shales weathers rapidly into shale fragments, producing few natural outcrops (Bassler, 1919). This formation weathers more easily than the overlying Conococheague and the Waynesboro Formations to the southeast, producing a pronounced valley between the two harder calcareous units. Within the Elbrook, there are also swales created by the differential weathering (due to higher silica content within some limestone and dolostone beds) within the strata; the result is a series of low hills that subdivide the valley and provided cover for discrete troop movement (Bassler, 1919). Ehlen and...
Whisonant (2008) contrasted this “higher-relief,” “dissected” terrain from the Conococheague to the northwest and differentiated the landscape as “undulating” (Conococheague) as compared to “rolling” (Elbrook). Tactically, from a defensive standpoint, undulating terrain is preferable over rolling terrain because the former extends the field of fire for small arms and especially artillery over a longer distance. Rolling terrain, in other words, provides at least partial cover for advancing troops, thus reducing the number of casualties inflicted by defenders at longer ranges.

The final carbonate unit that underlies the Antietam Battlefield is found farthest to the southeast in the region of the Lower Bridge (today referred to as “Burnside Bridge”). The Union advance to take this bridge occurred over the Waynesboro Formation, which is the oldest and thinnest of the three carbonate units (Bassler, 1919). This formation consists of sandstones, siltstones, shales, and dolostones. The Lower Bridge across Antietam Creek was built almost exactly at the contact between the overlying Elbrook Formation and the Waynesboro Formation.

The fighting during the battle progressed across the landscape in the same manner as the terrain described in the previous paragraphs (northwest to southeast) (Fig. 2). Union General McClellan first launched early-morning attacks against the Confederate left and across the relatively flat terrain underlain by the Conococheague limestone. Casualties during the initial stage of the battle were particularly high—the repeated advances with lack of topographic protection produced more than 8000 casualties.

By 9:00 a.m. on September 17, 1862, fighting shifted to the southeast, where Union Brigadier General William French’s division moved against the Confederate center, commanded by General D.H. Hill and anchored in the famous Sunken Lane. Here the offensive advantages offered by the rolling hills of the Elbrook Formation were countered by the defensive advantages of the trench-like sunken road. Assaults by French’s division continued until the Confederate forces occupying the sunken road—later renamed “Bloody Lane”—began to waver. The key moment in this portion of the battle arose when Union forces occupied a ridge underlain by a particularly erosion resistant portion of the Elbrook to the west of the lane. From here the Union soldiers commanded an enfilade firing position that was above and on the flank of the Confederate-held road, offering a firing position down the length of the enemy’s line. Unfortunately for the Union Army, as this portion of the Confederate line broke, McClellan failed to exploit the opening by not committing reserves to his battered II Corps.

The final phase of the day-long battle occurred in the southeastern portion of the battleground where Union Major General Burnside assailed the right of the Confederates line around mid-day. Instead of crossing Antietam Creek at multiple available fording localities, Burnside decided to force his way across the Lower Bridge while under considerable defensive fire from several Georgia regiments. This battle plan included attacking across the relatively open and unprotected Waynesboro Formation while under fire from Confederate soldiers well hidden in the overlying dolostone bluffs from the Elbrook Formation. The results were predictably disastrous, and the Union assault was delayed by hours.

When the bridge was finally taken, Burnside launched a renewed attack against the Confederate right flank, which was anchored on a topographic high just south of Sharpsburg. This assault was thwarted by the newly available reinforcements from Confederate Major General A.P. Hill’s division, which had just arrived from Harpers Ferry. By the end of this single day of fighting, nearly one in four participants, nearly 25,000 men, were wounded, killed, or captured.
Stones River (Murfreesboro), Tennessee

The battle of Stones River (or Murfreesboro) occurred over three days beginning on December 31, 1862. The Union Army of the Cumberland was repeatedly attacked by the Confederate Army of the Tennessee, but eventually held the field, thus providing a symbolic, if not Pyrrhic victory. The casualty rate of this battle was extraordinarily high—of the more than 80,000 soldiers involved in the fighting, nearly one third were killed, wounded, or went missing.

The Stones River battlegrounds are underlain by Middle Ordovician limestones (Fig. 4). These are amongst the oldest rocks outcropping in Tennessee (National Park Service, 2012). These outcrops, and the manner in which they were chemically and mechanically weathered, played an important role in providing critical defensive positions for the soldiers at the center of the faltering Union line.

The battle began early in the morning of December 31 with an ambitious attack by the Confederate Army, led by General Braxton Bragg, on the Union right. The relatively flat terrain over which this attack was conducted is underlain by the Middle Ordovician Ridley Limestone. This unit represents a 30–45-m-thick cryptocrystalline to very fine grained limestone with irregular bands of magnesium limestone and chert lenses (National Park Service, 2012). Sinkholes, springs, and well-developed karrens (or “cutters”) are all present on the battleground (National Park Service, 2012).

The Confederate assault continued to push back the Union right until the possibility of total defeat was realistic. The Union Army was vulnerable to being trapped and confined along the flood-swollen edge of Stones River. Only one escape route remained, the Nashville Turnpike, and Confederate forces were making a progressive advance toward cutting off this crucial escape route. Union commander Rosecrans desperately needed several hours to reform a new defensive line to protect this vulnerable ground behind the Union right and center.

During the Union delaying action in the center of the line, carbonate rocks provided their most pronounced defensive influence. The portion of the battlefield near the “Slaughter Pen” witnessed the most violent defensive struggle of the battle, and the natural karst karrens provided ideal defensive positions for the Union soldiers (Fig. 5).

Karrens form as the joints in limestone are progressively weathered by dissolution. As the joints widen and deepen, they trap organic debris, resulting in soil development and the growth of vegetation within the fractures. Microbial activity in the soil creates carbonic acid as CO2 is released into the vadose zone. This, combined with mechanical weathering from plant roots and repeated freeze-thaw cycles, creates a series of ~1.0–1.5-m-deep and ~1.0-m-wide natural trenches ideal for providing cover for troops under fire. Additionally, the original orientation of the joints at N45°E and N45°W results in karrens that join at right angles, further improving their defensive utility (potential for enfilade fire is reduced with natural [karren] barriers between the positioning of the troops along the long-axis of the line).

By the 1860s, nearly all land in this portion of Tennessee that was suitable for agriculture (i.e., not too rocky and suitable for soil development) had been cultivated. This obviously excluded the Slaughter Pen, and several other portions of the battlefield also remained wooded because of the proximity of limestone to the surface. At the center-left of the Union line, the Ordovician Ridley limestone again strengthened the defensive position. A cedar forest known locally as the “Round Forest” was referred to after the battle as “Hell’s Half Acre” because of the repeated and failed attempts to take the position by the Confederates. Unlike the karrens in the Slaughter Pen, the limestone here did
not provide cover; it did, however, inhibit rapid advance by the attacking forces and the trees provided a degree of defensive cover.

While limestone outcrops repeatedly slowed Confederate advances in the early and middle stages of the battle, the bedrock geology would dictate the location of the final turning point of the fight (Lewis, 2012). The West Fork of Stones River flows through a bedrock channel underlain by the Pierce Limestone, a cryptocrystalline to very fine grained, 8-m-thick unit (National Park Service, 2012). Only at the shallow McFadden ford could the attacking Confederates hope to cross and attack the Union left flank. Unfortunately for the attacking troops under the command of Confederate General John C. Breckenridge, this was the location where Captain John Mendenhall, Chief of Artillery for the Union Left Wing, had positioned nearly 60 cannon. The Confederate assault stalled at the ford under the sustained bombardment by the Union artillery, and the results of the futile final attack were a loss of more than one-third of the more than 5000-strong attacking force (Lewis, 2012).

Unlike at Antietam, characterized by larger-scale features in the geomorphology (rolling hills versus lower-relief terrain), the local rock features around Stones River provided defensive cover on a smaller scale. Instead of massed troop movements being shielded from fire by hills and valleys, individual soldiers and companies were shielded by the natural limestone trenches provided by the karrens or the forest cover above the limestone outcrops.

Chickamauga, Georgia

The role of carbonate dissolution features on the defensive positions and outcome of the Battle of Chickamauga, Georgia, is more subtle than at the earlier western-theater battle at Stones River. The battle began on September 19, 1863, with the Union Army of the Cumberland under the command of Major General William S. Rosecrans in position across Chickamauga Creek from Confederate General Braxton Bragg's Army of the Tennessee (Fig. 6). The carbonate rocks in this region of northern Georgia are similar in age and composition to those near Murfreesboro, located 150 km to the northwest. Variations in these rocks from Middle Ordovician Stones River Group and the Lower Ordovician Knox Group would determine the location of the Union Army's last stand, led by Union Major General George Thomas's XIV Corps (Fig. 6).

The terrain occupied initially by the Union Army was slightly higher than that of the Confederates in large part because of the higher concentration of erosion-resistant chert in the limestone (Henderson, 2004). The Union position was located on the Murfreesboro Limestone, which had a higher quantity of chert than the Lebanon and Ridley Limestones underlying the Confederate position. The first day's fighting yielded no clear victory but more than 15,000 casualties.

The fighting during the morning of the next day witnessed a complete failure in the Union line that had little to do with geology. A miscommunication within the leadership in the Union command led to a gap in the defensive line that was unknowingly and fortuitously exploited by an assault led by Confederate General James Longstreet. Only a single unit of mounted infantry—albeit infantry armed with fast-firing, seven-shot repeating Spencer carbines—delayed the Confederate attack until General Thomas reorganized his defensive position on Snodgrass Hill and Horseshoe Ridge. Thomas's position here was underlain by the Chepultepec Formation, which is known for its high chert content (Henderson, 2004). Despite 25 assaults by the Confederates, this geologically enhanced defensive position held until the Union Army could withdraw under the cover of darkness. The Confederates held the battlefield but at a cost of nearly 18,500 of the 34,000 total casualties.
Monocacy, Maryland

The Battle of Monocacy was fought on July 9, 1864, and represented the northernmost Confederate victory of the Civil War. Although the armies involved in this fight were not as large as in the previous three battles, the importance of the battle is demonstrated by the proximity of the battlefield to the Union capital city. Confederate forces under Lieutenant General Jubal A. Early defeated Union forces under Major General Lew Wallace, but the 24 h delay resulting from the battle proved detrimental to the advancing Confederate Army as it approached Washington, D.C.

Monocacy Junction is located 10 km south of Frederick, Maryland, in a region underlain by Cambrian limestones (National Park Service, 2008). Here, the Confederate Army's attack primarily followed the structural trend of the rock formations, and the rolling terrain provided ideal cover for discrete advance (Fig. 7). The battle opened with Early ordering a flanking attack across the Monocacy River toward Wallace's left flank. This advance was to be led by Brigadier General John McCausland's cavalry of ~1100 men. This attack crossed several members of the Frederick Limestone including the Lime Kiln Member and the shale-rich Rocky Springs Station Member (Southworth and Brezinski, 2003). As they approached the Union line, the four regiments of Union defenders remained hidden by the rolling hills of the Araby Formation, a metasiltstone. The differential weathering of the shale-rich limestone, limestone, and metasiltstone produced a high-relief landscape that proved ideal to the Union defenders led by Brigadier General James B. Ricketts. A single volley from his hidden troops decimated the advance line of the Confederate Cavalry. The Confederate General rallied his damaged forces to launch a second attack, but the defense remained too strong.

With the Union line revealed, Early sent Major General John B. Gordon's infantry division across the ford to renew the attack. Gordon launched an attack from three directions against both flanks and the center of the Union line (Fig. 7). Sustained Confederate artillery from across the river prevented Union reinforcements from arriving, and eventually the Confederate advance proved successful. Despite losing 65% of the 2000 casualties during the battle, Wallace successfully delayed the Confederate Army long enough so that the defenses on the outskirts of Washington, D.C. (and Baltimore, Maryland) could be reinforced.

DEFENSIVE POSITIONS ON CARBONATES DURING OTHER BATTLES

Differential weathering of limestones and dolostones also provided critical defensive positions in at least five other major battles during the Civil War (Table 1). Multiple battles during Confederate General Thomas Jackson's
Shenandoah Valley Campaign were fought at locales underlain by limestone as was the battle of New Market on May 15, 1864. The Union defensive positions during the disastrous battles for Franklin, Tennessee (November 30, 1864) and Nashville, Tennessee (December 15–16, 1864) were anchored on the high ground of the carbonate ridges produced by the Nashville dome. In the eastern theater, much of the battlefield of Spotsylvania Courthouse (May 8–21, 1864) in Virginia is also underlain by carbonate rocks, although the limestone ridges are not as pronounced as they are in Franklin and Nashville. These battles occurred late in the war and proved to be either defensive victories for the Union or bloody stalemates where the defenders could not be dislodged; troop emplacements for all three battles were dictated, at least in some part, by differential weathering of the underlying carbonate rock.

Figure 6. Troop positions during the Battle of Chickamauga superimposed on a geologic map of the battleground. Geologic map adapted from Lawton et al. (1976).

Figure 7. Troop positions during the Battle of Monocacy overlain on a geologic map of the region. Geologic map adapted from Southworth and Denenney (2006).
LIMESTONE WEATHERING AND ASSAULT TACTICS

Under ideal tactical and geological circumstances, attacking infantry could overpower defenders with little loss of strength. This occurred when overwhelming numbers were combined with superior terrain. Superior terrain included a landscape where troops can remain either hidden or shielded from artillery and small-arms fire as long as possible preceding the final assault. However, the terrain could not have a relief or roughness that made it too difficult to cross during attack (i.e., attacking uphill across uneven or dissected ground was especially difficult).

Defensive lines were especially difficult to dislodge if the underlying carbonate rock provides some degree of protection from fire. The karrens at the center of the Union line at Stones River were a perfect example because the carbonate rocks essentially provided elevated trenches for the defenders.

An ideal defensive position, geologically, was found at Little Round Top, Gettysburg. This position, anchored in igneous diabase and not carbonate rock, nevertheless provided an interesting study (Fig. 8). Here the steep terrain made attack out of Devil’s Den or the Wheatfield difficult under the heavy Union fire from above. Secondly, the weathered boulders on the top of the hill provided strong breastworks, which were quickly assembled before the

### TABLE 1. CHARACTERISTICS OF BATTLEFIELDS WHERE GEOLOGY PLAYED A SIGNIFICANT ROLE IN DETERMINING DEFENSIVE TACTICS

<table>
<thead>
<tr>
<th>Battlefield</th>
<th>General rock description</th>
<th>(Primarily) Attacking army forces</th>
<th>(Primarily) Defensive army forces</th>
<th>(Primarily) Attacking army casualties*</th>
<th>(Primarily) Defensive army casualties*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battleground underlain by carbonate rock</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Antietam</td>
<td>Mixed carbonates with shale</td>
<td>USA 87,000</td>
<td>CSA 45,000</td>
<td>11,650</td>
<td>9100</td>
</tr>
<tr>
<td>Chickamauga</td>
<td>Limestone with some chert</td>
<td>CSA 65,000</td>
<td>USA 60,000</td>
<td>16,986</td>
<td>11,413</td>
</tr>
<tr>
<td>Franklin</td>
<td>Limestone</td>
<td>CSA 33,000</td>
<td>USA 30,000</td>
<td>5500</td>
<td>1222</td>
</tr>
<tr>
<td>Missionary Ridge</td>
<td>Limestone and dolostone</td>
<td>USA 56,359</td>
<td>CSA 44,010</td>
<td>5475</td>
<td>2521†</td>
</tr>
<tr>
<td>Monocacy</td>
<td>Limestone and shale</td>
<td>CSA 14,000</td>
<td>USA 5800</td>
<td>-700</td>
<td>-900</td>
</tr>
<tr>
<td>Nashville</td>
<td>Limestone</td>
<td>USA 55,000</td>
<td>CSA 30,000</td>
<td>2945</td>
<td>-1500†</td>
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<tr>
<td>New Market</td>
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<td>USA 6300</td>
<td>-525</td>
<td>616</td>
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<tr>
<td>Perryville</td>
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<td>CSA 16,000</td>
<td>USA 22,000</td>
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<td>3805</td>
</tr>
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<td>CSA 35,000</td>
<td>USA 41,400</td>
<td>9239</td>
<td>9200</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>365,459</td>
<td>284,510</td>
<td>56,193 (15%)</td>
<td>40,277 (14%)</td>
</tr>
</tbody>
</table>

| Battleground underlain by non-carbonate rock |                          |                                   |                                  |                                       |                                       |
| Atlanta               | Gneisses and metasedimentary | USA 34,863                        | CSA 40,438                        | -3000                                 | -4100                                 |
| Chancellorsville      | Metamorphic and igneous    | USA 60,892                        | CSA 123,868                       | 10,746                                | 11,278                                |
| Fredericksburg        | Metamorphic and sand and/or gravel | USA 114,000                   | CSA 72,500                        | 10,884                                | 4742                                  |
| Gettysburg            | Diabase, sandstone, and shale | USA 71,700                        | CSA 93,920                        | 22,638                                | 17,684                                |
| 1st Manassas          | Diabase, sandstone, and shale | USA 34,000                        | CSA 35,000                        | 1584                                  | 1969                                  |
| 2nd Manassas          | Diabase, sandstone, and shale | USA 55,000                        | CSA 70,000                        | 8335                                  | 9931                                  |
| The Wilderness        | Metamorphic and igneous    | USA 101,895                       | CSA 61,025                        | 14,283                                | 9343                                  |
| TOTAL                |                          | 472,350                           | 506,751                           | 71,488 (15%)                         | 59,047 (12%)                          |

| Battleground underlain by unconsolidated or partially lithified sediments |                          |                                   |                                  |                                       |                                       |
| Cold Harbor           | Sand, gravel, and clay    | USA 108,000                       | CSA 59,000                        | 10,921                                | 4164                                  |
| Fair Oaks             | Sand, gravel, and clay    | USA 39,000                        | CSA 34,000                        | 5774                                  | 4384                                  |
| Gaines Mill           | Sand, gravel, and clay    | USA 57,018                        | CSA 34,214                        | 7885                                  | 4001                                  |
| Malvern Hill          | Sand, gravel, and clay    | USA 30,000                        | CSA 27,000                        | 5110                                  | 2189                                  |
| 2nd Petersburg        | Sand and clay             | USA 62,000                        | CSA 38,000                        | 10,201                                | 3100                                  |
| Shiloh                | Sand and clay             | USA 66,812                        | CSA 44,699                        | 9740                                  | 10,162                                |
| TOTAL                |                          | 362,830                           | 236,913                           | 49,631 (14%)                         | 28,000 (12%)                          |

Note: Casualty rates were not appreciably higher for attacking troops on carbonate battlefields compared to attacking soldiers across landscapes underlain by non-carbonate rocks or unconsolidated strata.

*Casualties listed here are killed plus wounded only (does not include missing or captured).
†~4500 soldiers also surrendered. Abbreviations: CSA—Confederate States of America; USA—United States of America.
attack. Limestone produced similar slopes (Fig. 9) and relief for defending (e.g., Snodgrass Hill at Chickamauga; Fig. 9B), but it usually did not weather into boulders that were used for breastworks.

The Confederate assaults at Gettysburg on the second and third day of battle also provide interesting comparisons with similar magnitude assaults at other battlefields across carbonate rocks. Compare, for example, the Confederate attack on Snodgrass Hill and Horseshoe Ridge at Chickamauga (Fig. 9B) with the Confederate attacks across Devil's Den toward Little Round Top at Gettysburg (Fig. 9E). The Union defenders in both situations had outstanding fields of fire across the landscape because they were situated at least 40 m above the attacking Confederate infantry. The difference in elevation in both cases was related to the durability of the underlying rock: at Gettysburg, Little Round Top is formed from Jurassic diabase with the surrounding landscape underlain by Triassic sandstones and shales (Stose and Bascom, 1929; Brown, 1982), whereas at Chickamauga the difference in elevation was the result of enriched versus non-enriched limestones (Henderson, 2004). Snodgrass Hill is an extension of Missionary Ridge, a formation with erosion-resistant chert interbedded.

While Little Round Top and Snodgrass Hill are superficially similar with respect to their slope and invulnerability to successful attack, Little Round Top offers a better defensive position resulting from the weathering of the outcropping diabase. This exfoliation and spherical weathering provides an abundant supply of boulders large enough to stop small-arms fire, yet small enough to be transported and piled by soldiers. As a result, the top of Little Round Top is ringed with diabase breastworks, making the high-relief defensive position even more formidable.

Careful positioning of Union defenders on Snodgrass Hill also took advantage of the geology. Artillery and infantry were positioned just behind the crest of the hill in a reverse-slope position (Fig. 10). The resulting defensive position benefited from the slope of the crest because cover was provided for the defending soldiers without limiting the fields of fire. The impact of rifle and artillery fire from attacking Confederate forces that ricocheted or missed was also minimized because anything other than a direct hit would continue an upward trajectory before falling well behind the Union position. The tactics developed by Union Colonel Charles Harker to take full advantage of this crest are well summarized by Woodworth (1999, p. 74). The Union commander divided his troops into two lines at different distances on the reverse slope of the crest. When attacked, they would essentially alternate volley fire before falling back under the shelter of the hillcrest to reload and reform. The resulting defensive arrangement effectively and successfully minimized exposure to the attacking enemy fire while maximizing the defensive rate of fire.

At Stones River, outcropping limestone offered clear defensive benefits for the Union Army in the form of karrens; nevertheless, the shallow soil above much of the limestone provided more subtle benefits for the attacking Confederate troops as well. The gently sloping ground in front of the center of the Union line is similar to the ground in front of the Union center at Gettysburg on July 3 (cf. Figs. 9C and 9F). However, nearly all of Pickett's Charge occurred across Triassic sandstones and shales, which produce fine soils for agriculture. As a result, these fields, which had been cleared of trees by local farmers, provided a clear field of fire of nearly 1500 m for the Union artillery and infantry. On the Stones River battleground, the outcropping (or nearly outcropping) limestone prohibited agriculture on large portions of the battlefield, and the surviving forests restricted visibility and the effective range of the Union artillery and rifled muskets.

At Antietam, the contrast between the casualty rates on the flatter northern portion of the battlefield surrounding the cornfield and the rolling hills around the more southern portions of the battlefield demonstrated the increased effectiveness of rifled muskets, and especially artillery, over lower-relief carbonate terrain. During the battle, forces from both armies were armed with single-shot muskets or rifled muskets that had a maximum sustained firing rate of two to three shots per minute. Smoothbore or rifled artillery was even slower to reload, aim, and fire. Attacking forces across the flatter terrain faced multiple volleys from defenders across hundreds of meters of open ground, whereas defenders in the rolling terrain were only able to fire two or three times at most before the possibility of being overwhelmed and overrun by attacking infantry. The hills shielded troop advance, and attacking soldiers were only visible for the last few hundred meters of advance.

The rolling hills surrounding the center of the Confederate defensive line at Antietam provided advantages for the attacking Union Army as well. Although well positioned in the trench-like road, visibility to the front of the Confederate line toward the most likely vector of attack by the Union infantry was limited.
Note that the last portion of the Union attack (Fig. 9A) was over a gentle ridge and downhill into the sunken road. Much of the Union advance would have been screened by this hill with the Union infantry only emerging in front of the Confederate defenders as they crested this final hill on the Roulette farm (Fig. 11). Given a realistic rate of advance by the Union infantry of 12 km/h, the final assault across this hill would have taken less than a minute and a half (200 m at ~3 m/s). This short time frame would have given the supporting Confederate artillery time for only an initial aimed volley followed by a rapid reloading and a second hurried barrage of canister. If the outnumbered Confederate infantry in the sunken road below the artillery began firing as the attacking soldiers crested the hill, they would have, at best, time for three shots. Under combat conditions and across a smoke-filled landscape, it is likely the terrain limited the defenders to a single shot from the artillery and one or two from the infantry.

Official reports by commanders on both sides of the conflict along the Confederate center make reference to the rolling terrain. Some commanders used the terrain for concealment of approach, while others used it as cover from fire. Confederate Brigadier General R.E. Rodes, for example, remarked in his official report of the fighting around the sunken road: “The enemy came to the crest of the hill overlooking my position, and for five minutes bravely stood a telling fire at about 80 yards, which my whole brigade delivered. They then fell back a short distance, rallied, were driven back again and again, and finally lay down just back of the crest, keeping up a steady fire, however” (Official Records, 1887).

Multiple historians have studied the range of engagement during Civil War battles (see Hess, 2008, for a thorough discussion) and found that the average range of rifle fire was only ~100 m. Given that the maximum range of accurate fire from a rifled musket exceeded 400 m, this shorter estimated range is somewhat unexpected. After all, the rifled musket offered at least a fourfold increase in range over the earlier smoothbore musket used during the Napoleonic era; yet the average range of fire was only ~20 m distant (Nosworthy, 2003). This shorter range is often attributed to the limited training of the soldiers, combined with poor visibility from non-smokeless black powder. However, it is also possible that the range was restricted because of the terrain—soldiers could not fire at an enemy that was not visible behind a rolling hill or limestone ridge.
CONCLUSIONS

Carbonate rock provided advantages to defending soldiers during the Civil War on multiple scales. At the smallest level, karrens provided natural elevated and armored trenches. On a large scale, differential weathering between adjacent formations provided high ground for the positioning of defensive lines.

Not all landscape features created by carbonates were beneficial to defenders. Outcropping dolostone and limestone prohibited use of the land for agriculture, and the resulting forests provided cover for advancing troop movement and reduced the effective range of artillery and small arms. Rolling terrain reduced the distance over which assaulting troops had to pass under fire before reaching the defending lines.

Overall, carbonate rocks appear to have created landscapes that favored defensive tactics if either local weathering produced uneven ground or karrens or differential weathering produced slopes on enriched limestone overlooking flatter or undulating terrain and not a rolling landscape. Examples of commanders exploiting this advantage are numerous, including Confederate General Thomas “Stonewall” Jackson in the Shenandoah Valley and Union General George “The Rock of Chickamauga” Thomas in northern Georgia. Nevertheless, casualty rates (killed and wounded only—excluding missing soldiers) were not appreciably higher for attacking troops on carbonate battlefields (Table 1). Analysis of casualty figures (killed and wounded only, not missing) indicates equivalent losses (~15% of troops engaged) whether soldiers were attacking across carbonate rock, non-carbonate rock, or unconsolidated sediments. Soldiers defending ground underlain by limestones and dolostones suffered a marginally higher casualty rate (14%) than those defending terrain above non-carbonate rocks or unconsolidated sediments (12%). This suggests—in a restricted manner—that the local smaller-scale defensive advantages provided by limestone, such as karrens, were not as important as the regional-scale advantages for attacking troops, including rolling terrain or forest cover. In summary, the aforementioned defensive benefits provided by the limestones and dolostones were balanced by the concealment created by rolling terrain or forest cover.

While the relationship between geology and Civil War tactics has been well investigated at Gettysburg, the more nuanced relationship resulting from carbonate geology provides a similarly interesting study at multiple other battlegrounds. Additionally, it is doubtful that a better example of a geologically enhanced defensive position survives from the Civil War than the karrens from the center of the Union line at Stones River (Fig. 5).
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