All New

mountaineers outdoor basics

Modern WILDERNESS Navigation

Using GPS in Combination with Digital Maps, Paper Maps, Compass & Altimeter

FIRST EDITION

Steve McClure

MOUNTAINEERS PROGRAMS

An Invitation to Students and Instructors: Join Our Exciting Navigation Textbook Project!

We are on an exciting journey to create a leading-edge navigation textbook for the outdoor community, and we want you on board!

In 2016, I was honored to revitalize the navigation chapter for "Mountaineering: The Freedom of the Hills, 9th edition." Building on that experience, I'm crafting this completely new navigation textbook that steps beyond the traditional, pre-GPS approaches. This book is for the Mountaineers navigation students in our revamped classes and a wider audience through national publication.

This is where you come in! The Mountaineers thrive on the power of our volunteer community. As we offer this draft book for free, we invite you to contribute by sharing your feedback and ideas. Students, your insights are invaluable in shaping a text that truly resonates and educates. If something doesn't work for you, it likely won't work for others. Let's perfect it together.

Instructors, your perspective is key in identifying what connects with students, what needs clarity, and what might be missing. Your expertise will help make this book a comprehensive and understandable guide to modern wilderness navigation.

Students and instructors alike, I welcome your contributions in any form: an email, annotated text or diagrams, comments in the PDF, or even a phone call. Every piece of feedback is a step towards creating a comprehensive and understandable guide.

Here's to staying found!

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Feedback Suggestions:

- Humor Check: What jokes or humorous comments didn't land?
- Storytelling Effectiveness: Which stories were enlightening, and which missed the mark?
- Your Stories: Do you have a personal experience that could bring a point to life?
- Visual Aid Impact: Which illustrations or maps clarified concepts, and which fell short?
- Creative Contributions: Any ideas for visuals that could simplify complex topics?
- Identifying Gaps: Where is information lacking?
- Clarity and Accuracy: Which parts of the text are unclear, incorrect, or exceptionally clear?
- Relevance and Detail: Are there sections that seem unnecessary or need more elaboration?

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INTRODUCTION

Ain't No Sunshine

When we yearn, the mountains beckon. When we listen, the rivers gurgle invitations. When we unfold our maps, the dotted trails weave quiet adventures enough for a hundred lifetimes, enough for us all. Accepting the invitation of wilderness requires the ability to research and plan a route, keep track of our start and progress, and make confident assessments while underway.

On the ideal wilderness excursion, the sun is out, the view is grand, and we can lean heavily on our visual navigation techniques with a physical map and compass. But the concepts of this book were forged in the Pacific Northwest, where gray drizzle, dense evergreens, and challenging topography are the norm.

Low-visibility conditions have confused and sometimes threatened wilderness navigators and have dissuaded many more from stepping into the unknown. None of us wishes to set out ill-prepared or inadequately equipped nor attempt a route beyond our ability. This book empowers exploration by adding a rich set of digital instruments to the traditional physical tools. However, understanding the limits of these electronic tools is as important as understanding their usefulness: technology can fail, batteries will be depleted, and communications are limited in most remote locations. The modern navigator embraces the new tools as adjuncts to, not replacements for, our traditional tools.

This book is divided into three sections: Part I, High-Visibility Navigation by Sight; Part II, Low-Visibility Navigation by Instrument; and Part III, Special Topics.

Part I covers the foundational ideas and techniques of the map and compass. The early chapters cover basic map use, concepts that carry over to the digital world. Physical lines of position, handrails, and backstops will help keep the navigator's situational awareness high and their footsteps on course. The ultra-reliable compass not only remains important in the GPS era, but is easier than ever to use.

Part II adds a rich set of tools that work in high- or low-visibility conditions. Altimeters, digital maps, GPS devices, and satellite communication expand navigation beyond what can be seen, allowing travelers to explore spaces unknown to them. For trips where things fall apart, Part II discusses how to use SATCOM to organize an efficient rescue with first responders.

Part III details how to prepare for a journey and execute it with confidence under the banner of *navigation workflow.* Part III also introduces additional phone apps to assist exploration and covers the unique needs of climbers, backcountry skiers, adventure travelers, orienteers, military, search and rescue, overlanders, and coastal adventurers.

This book is more than one author's opinion; it is the collective wisdom of hundreds of instructors, honed on thousands of students with a legacy reaching back to the founding of The Mountaineers in 1906. This book is about more than the five navigational instruments. It is an invitation to visit wild backcountry places with a quiver of tools and techniques to get you there and back safely. This book aims to impart the skills necessary to explore the wilderness and engage in the ultimate scavenger hunt for primeval beauty. In stretching ourselves to travel farther afield, we can dilute our human impact and may just find there is room for us all. We may even find these wild spaces are worth fighting for!

THE MOUNTAINEERS

The Mountaineers is a nonprofit outdoor community of 16,000 active members in the Pacific Northwest. Founded in 1906, we've been getting people of all ages outside safely and responsibly for over 100 years. We host hundreds of monthly courses and activities - all led by volunteers - to offer ways to get outside and connect with others and the natural world. We think it's important to introduce people to the outdoors early and often, and we work to protect the outdoor experience for future generations. We believe everyone should feel belonging in the outdoors, and we're striving to connect people, especially those who have been historically excluded, with the transformative power of outdoor experiences.

Remember the cartographers' saying, "What's on the ground before you is the truth. Not your map or GPS screen."
—John Godino, The AlpineSavvy.com Blog

INTRODUCTION TO SECTION I: HIGH-VISIBILITY NAVIGATION BY SIGHT

Standing upright on the savanna, our early ancestors' newfound mobility allowed wider-ranging foraging and travel to seasonal bounties in a landscape rich with resources but dangerous. Under the endless African azure, it was here that the seeds of navigation were sown.

Evolution sharpened our spatial awareness, allowing us to weave intricate mental maps from animal spoor, sun shadows, and the habits of the wind. Every return from a trek, every landmark etched in memory, every tale of a distant oasis, was a building block of navigation.

Like our ancestors, these intricate mental maps evolved. Simple terrain recognition gave way to pathways marked by cairns and trail markers. The sun and stars allowed for natural navigation techniques, their movements offering silent directions across vast distances. Eventually, physical maps emerged to supplement the collective memory and experience.

Over time, humanity's quest to navigate with precision led to the invention of compasses, used for the last millennium, and altimeters, used for the past two and a half centuries. These tools measured the unseen force of magnetism and the subtle changes in atmospheric pressure, expanding humanity's ability to explore the world.

The evolution of GPS and its impact on most of our wilderness navigation practices was the catalyst for this book. Current best navigation practices involve five tools, some ancient and some modern. While GPS, satellite communications, and electronics are surpassing traditional tools, the synergy of these tools empowers us to explore wild spaces with unprecedented efficiency and safety. Working collaboratively, these tools offer the best of both worlds. The inflexible but ever-reliable paper map is supported by digital versions that we can customize to our needs. The compass is now more user-friendly, thanks to GPS-supplied bearings. Altimeters, using both air pressure and GPS, provide two elevation readings, allowing for local accuracy when calibrated and weather-resistant precision without calibration. Simple satellite communications are now accessible, providing backcountry coordination and a lifeline to emergency responders. This section provides a guide to the first two of our five tools, the map and compass, in both their ancient and modern forms.

Chapter 1: First Tool: Modern Maps will plunge you into digital, home-created, and commercial maps by allowing you to use QR codes to download samples immediately. Then, you will be introduced to the fundamentals of map reading, including map scale, contour lines, declination, distance, and landforms.

Chapter 2: Map-Only Navigation will begin your learning about using this core tool of modern wilderness navigation. It will cover the overarching principle of physical and instrument lines of position. You will learn how to use lines of position (LOPs) to answer the question “Where are we?” with three levels of precision. In addition, you’ll learn to use two special LOPs: 1) handrails, which are LOPs that can guide us toward our target, and 2) backstops, which are LOPs that run crosswise to our direction of travel, alerting us that we are approaching or have traveled past the next turn or destination. The chapter concludes with “trail dead reckoning,” the most straightforward technique in this book and one of the most practical and frequently used, especially on trails.

Chapter 3: Second Tool–Compass will get the skeptic past their reluctance by showing how this tool is more relevant and easier to use in the GPS era. You will learn about the types of compasses, the mechanics of reading bearings, and adjusting for declination. You’ll then learn how to put the compass to work in the field or on a map, using bearings derived from GPS, map measurements, and compass field measurements. You’ll meet Fred and put him in his shed while avoiding the dreaded 180° errors.

Chapter 1

First Tool: Modern Maps

FIRST MAP

Beryl Markham, the pioneering Kenyan aviator, beautifully captured the significance of maps when she wrote, “A map says to you, 'I am the earth in the palm of your hand. Without me, you are alone and lost.’” This sentiment emphasizes the vital role that maps play in navigating the wilderness. Less eloquently, but more precisely, the US Army’s land navigation handbook says, “A map is a graphical representation of a portion of the earth’s surface drawn to scale, as seen from above.”

Our journey of wilderness navigation begins with maps, and their exploration is similar to plunging into a mountain lake, best done without hesitation. Our initial dive into the world of maps will reveal essential elements such as map types, compass directions, scale, and contour lines. This understanding will enable us to interpret maps, recognize their warnings, and stay found.

Download the maps in Figures 1-1 and 1-2 with your laptop or phone from the QR codes or URLs below. We will delve into the details of maps, but for now, carefully look and decipher what you can from these two examples of topographic maps made for Mount Rainier National Park:

- **Zoomed-out 1:50 000 scale map: Eastern side of Mount Rainier National Park, Washington State, US.** This topographic map offers a zoomed-out perspective of the park, ideal for comprehensive trip planning. The topographic lines help us envision the shape of the landscape. By zooming in on your computer or examining a printed version, try to differentiate between high ground and low. Which areas are ridges, and which areas are valleys or gullies? Can you envision the slow-moving rivers of glacial ice flowing from Rainier’s summit down its flanks? This home-created map was made using a browser-based service called CalTopo. It was built on a base map published by OpenStreetMap (OSM), a Wikipedia-like world mapping project. As you explore this map, challenge yourself to find as many of these essential map elements as you can:
    - **Map scale.** The map’s scale is shown as a graphical bar, as a ratio, and in words.

KEY TOPICS
MAP TYPES
MAP PARTS
READING MAPS
MAP PRACTICE

The nuances of map scales are covered below under Margin Matters.

- **North, East, South, West.** Find Burroughs Mountain on the north end of the map. Find Meany Crest on the east side of the map. Find the famous Lodge marked as "Paradise" on the south side of the map. Find the summit of Mount Rainier toward the west side of the map.

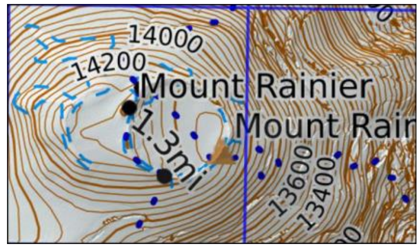


Fig. 1-1. Map 1: Eastern side of Mount Rainier National Park. CalTopo.com/p/G7DBR

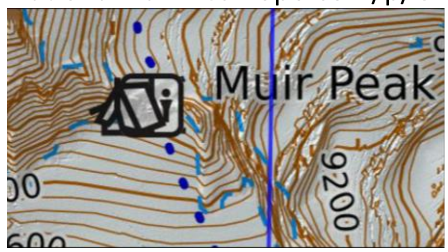


Fig. 1-2. Map 2: Route to Camp Muir in Mount Rainier National Park. CalTopo.com/p/9TH8T

- **Declination diagram.** This diagram indicates the directions of north and magnetic north, which is the direction compasses point. Declination (see below) is the difference in degrees.
- **Universal Transverse Mercator (UTM) grid lines.** These metric-based lines locate GPS coordinates on maps. On this map, each square is 1,000 meters (1 km) on a side. UTM grid lines are preferred to latitude and longitude lines for land navigation. Longitude lines are the farthest apart at the equator, converging as they move north or south from there, making them difficult to use for distance calculations.
- **Camp Muir Trail.** Now, find the trail to Muir Peak or Camp Muir. It starts at Paradise, continues close to McClure Rock, and continues up the Muir Snowfield. We will examine this route next.

2. **Zoomed-in 1:25000 scale view: Route to Camp Muir in Mount Rainier National Park.** This map's zoomed-in magnified scale is especially good for detailed trip planning and navigating while en route. Compare this map to the zoomed-out view. This topographic map was also home-created using CalTopo and built on a base map from OSM. Compare the two maps to look for significant differences:
    - **Map scale.** Which map shows more details of the hike to Camp Muir? How much distance does 1 inch (about 2.5 cm) show on each map? Note the differences in how the map scales look.
    - **UTM grid lines**. The UTM grid lines on this map are still 1,000 m (1 km) on each side. Does it make sense that the squares on the zoomed-out map are smaller than those on the zoomed-in map?

- **Best use.** Which map is more helpful in finding your way to the trailhead and determining the best vantages for views? Which map is more useful in hiking and navigating if the visibility diminishes?

MAP TYPES AND WHERE TO GET THEM

Maps are the primary tools that help us plan and navigate our journeys. This primary navigation tool is produced in physical and digital forms. Both map types synthesize vast amounts of data about a region in different but convenient formats, each with distinct advantages and disadvantages.

Physical (paper) maps. There is a robust simplicity to physical maps. Such maps are typically called “paper” maps, whether printed on paper, plastic, or other material. Paper maps don’t need batteries and are not easily broken. They give us the big picture of the landscape, allowing us to see 10 to 80 times more map area than the screens of today’s largest phones. However, the physical map has a border that forms an absolute limitation to its information. This contrasts with a digital map that can be easily downloaded for a vast region such as an entire US state or European country. Paper maps also lack a “you are here” arrow to show your location. Unless printed on plastic or special paper, they can become wet and disintegrate or blow away in the wind. They cannot be updated without repurchasing or reprinting.

Digital maps. Digital maps are computer files displayed on an electronic screen. In navigation, we primarily display digital maps on the screen of a GPS-enabled device, typically a phone with a GPS app. A digital map uses the device’s GPS capability to show the current location. It can record a location as a waypoint, or a series of locations recorded at intervals as a GPS track. Digital maps are created using two basic methods (covered in more detail in Chapter 5):

- **Static (raster) digital maps.** A static digital map is a traditional paper map that has been scanned. Referred to as a "raster" map, it produces a fixed image that allows slight zooming but doesn't alter details proportionally. Zooming in on a raster map is like using a magnifying glass on a paper map; zooming out is like stepping back to see multiple maps taped together. Zooming reduces or enlarges the entire image without modifying its content.
- **Dynamic (Vector) digital maps.** Most digital maps are dynamic "vector" maps generated in real-time by GPS apps based on a database, dependent on the user's selected zoom level. A vector map’s features are assembled from points, lines, polygons, shading, labels, and symbols. When zooming in or out, the software dynamically re-renders the map's features, adding or removing labels and symbols for optimal resolution. This

results in a sharp and usable map at high and low zoom levels, with elements like place names and contour line elevations adjusted to maintain readability. Smaller details, such as minor roads and trails, become visible as you zoom in but are limited by the available database. Conversely, these finer details may disappear when zooming out to prevent a cluttered and unreadable map. Vector files in GPS devices typically have smaller file sizes than raster files, allowing users to download larger map regions than is strictly necessary. This flexibility proves advantageous, especially when navigating to a trailhead or adapting plans.

Digital maps are used for planning, printing, and GPS navigation. First, we engage with digital maps on our home computers to meticulously plan trips, considering factors like routes, weather conditions, and avalanche forecasts, and then customize them with relevant waypoints and routes. Second, we print paper copies of these customized maps to use during the trip as companions to the maps we keep in digital form. Third, we export our customizations to a GPS device to navigate during our trip. The process of creating digital maps and preparing our GPS devices is (will be) covered in the context of trip planning in Chapter 7, Navigation Workflow.

Digital maps with a GPS app can pinpoint our location, zoom in or out, and record our footsteps in a GPS track. For any point on the map, they can give us its elevation, slope, distance, and a bearing to point the way. Mapping apps allow swift transitions between various map types and even satellite imagery. However, tiny digital maps depend on fragile, expensive battery-driven electronics, the failure of which would leave you without a map, a potentially dangerous situation. To address this, protective cases, backup power, and especially redundant devices can partially mitigate these potential risks. Printing and protecting a paper map (even in a humble 1-gallon Ziploc bag) is excellent insurance against electronic failure. A more comprehensive exploration of digital mapping methods, digital map types, overlays, and map downloading is covered in Chapter 5.

Adopting a hybrid approach using digital and paper maps is the best practice for modern wilderness navigation. Still, a digital map can be used carefully as your exclusive map when a physical map is unavailable. Refer to the inset "Using Only Digital Maps" for guidelines on using only digital maps safely.

TABLE 1-1. A COMPARISON OF THE TWO BASIC MAP TYPES.		
Feature	**Digital Maps on a GPS Device**	**Physical Maps**
"You are here" arrow	Yes. Location is shown on the digital map with an arrow.	No.
Portability	Easy portability using GPS devices.	Can be bulky and heavy when carrying maps to cover a large area.
Durability and technical dependence	Fragile electronic devices are vulnerable to damage from water, extreme temperatures, accidental drops, and technical issues, such as low battery, signal loss, or system updates.	Do not require electronic devices or power. Typically printed on tear-resistant and waterproof materials. Difficult to use in wind and can blow away.
Broad perspective	Small screen size challenges a broad perspective. The ability to store large maps in memory and zoom out allows access to more detail about a large region.	Paper maps provide a broad perspective, which allows users to visualize and remember a wilderness area and plan accordingly.
Interactive features	Zooming, panning, and search functions. Ability to record waypoints and tracks. Some GPS devices can send real-time GPS tracking information via satellite.	Fixed scale and limited detail due to size constraints.
Updates	Updated regularly for changes to trails and roads. Can be updated with overlays to show some real-time data, such as weather and avalanche forecasts.	Physical maps are static and cannot be updated without reprinting or repurchasing. Commercial maps are updated infrequently.
Customizable	Highly customizable.	Commercial maps are not typically customizable. See the note below about home-created maps.
	Note: Online mapping services allow for significant digital and physical map customization. Map region, type, scale, and shading can be specified and enhanced with waypoints, routes, tracks, and information overlays.	

ACQUIRING MAPS

In this golden age of mapping, reliable maps are immediately available for almost any place you want to go. Digital maps can be downloaded directly to our phones, online services allow us to create custom maps to print at home, and commercial publishers supply physical maps through retail stores.

Acquiring digital maps. Digital maps are typically acquired through mobile or tablet mapping apps, GPS watches, or dedicated GPS devices. While phone apps offer dozens to hundreds of map types, dedicated GPS devices tend to have only one. Users can better understand the landscape from each map's unique perspective by downloading multiple digital map types. Most digital maps are included with an online subscription and typically use "all-you-can-eat" pricing, allowing us to plan excursions to any corner of the earth.

A digital mapping revolution is happening, and millions of GPS enthusiasts contribute to it through OpenStreetMap (OSM). Inspired by Wikipedia, this crowdsourced project is where people map the world. OSM has the most up-to-date information about trails and roads worldwide, from back alleys in Marrakesh to trails in the Swiss Alps and Pacific Northwest Cascades. The OSM database allows cartographers unlimited free access to create custom maps for backcountry travel, cycling, paddling, or driving. These maps are the backbone of most phone GPS applications.

For more on digital maps, including raster versus vector maps, map overlays, and downloading, see Chapter 5: Apps and Maps.

Gaia GPS enables users to create, download, and print custom topographic maps. These services allow users to customize their maps by adding routes, waypoints, and other information. The navigator can choose the locations for each journey from various seamless base maps and then pick the appropriate map scale, overlays (such as shading), grid lines, and paper size. The resulting maps can then be printed and downloaded to GPS devices. These services are handy for

USING ONLY DIGITAL MAPS

Late changes in plans or the unavailability of a printer or a commercial map can make digital maps the only available option. Digital maps can be relied upon exclusively, with caution and redundancy. To use them safely, ensure devices are fully charged, carry ample backup power in a power bank, and have all necessary maps and layers downloaded onto your devices.

Each group should have at least one fully charged redundant device with an appropriately configured app and relevant maps downloaded. Additional steps should be taken to partially mitigate the risk of not carrying a paper map. See Chapter 7: Things Fall Apart, Creating a Redundant GPS Device.

Over-reliance on the phone as the exclusive navigation tool frequently puts parties at risk. Search and rescue groups say that when a group in trouble can make a call, their first words are often, "I gotta talk fast. I only have 5% of my battery left."

backcountry trip planning by allowing users to check targeted weather forecasts, avalanche forecasts, current snow depth, and satellite images, updated globally every few days. Such services are covered in depth in Chapter 6: Navigate Like a Pro.

Acquiring commercial maps. Topographic maps, essential for wilderness navigation, are available through commercial entities and government agencies. The United States' interest in cartography dates back to the Lewis and Clark expedition in 1804, initiated by President Thomas Jefferson. Following this, the establishment of the United States Geological Survey (USGS) in 1879 significantly advanced the production of detailed topographic maps. Today, these maps, encompassing diverse landscapes, are accessible in physical and digital forms through the USGS, Forest Service, and National Park Service, supporting various activities from scientific research to outdoor exploration.

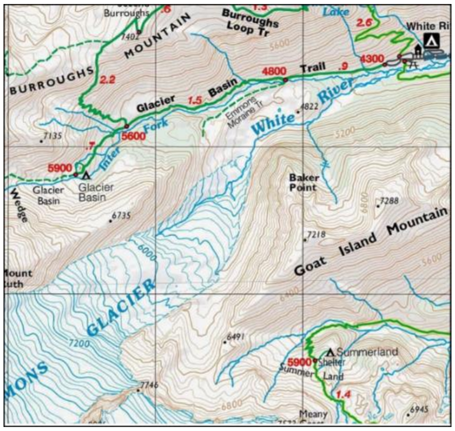
Many other national governments produce detailed topographic maps that show natural and human-created features of their respective countries. Some examples include the Ordnance Survey (OS) in the United Kingdom, the German Federal Center for Cartography and Geodesy, Natural Resources Canada, and The Federal Office of Topography in Switzerland.

Private companies such as Green Trails Maps, National Geographic Maps, and Tom Harrison Maps produce high-quality topographic maps for popular outdoor recreation areas. Benchmark Maps and DeLorme Publishing Company (part of Garmin Ltd.) publish state-wide atlases for select US states.

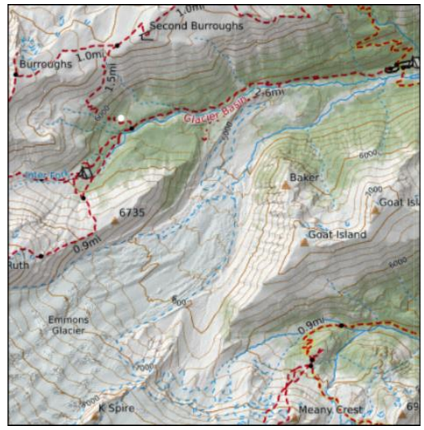
USGS Maps. Formerly the gold standard of US topographical maps, few navigators now bother to either purchase USGS maps or download them for free. Maps published by the USGS from 1884 through 2006 have been scanned and are available for download from USGS's Historical Topographic Map Collection. These maps are a static archive and, therefore, are permanently outdated. The modern vector-based (see Chapter 5: Apps and Maps) series, US Topo, as of 2023, will not have complete trail data for many years. When USGS maps are used, it is typically through a digital device or printed with an online service to take advantage of seamless, slightly zoom-able, customizable, and shade-able versions.

MAP COMPARISONS

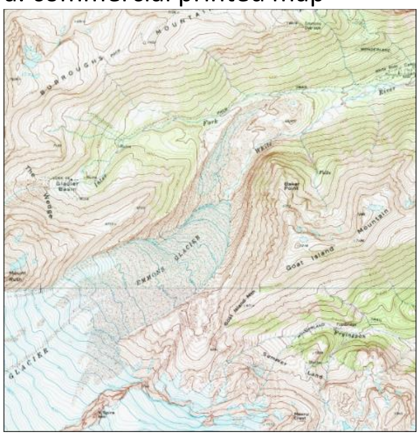
Compare these six examples of maps for Mt. Rainier's northeast side in Figure 1-3. These maps show the second most popular climbing route to the summit, up the Emmons Glacier. The maps are of the same area, each adding different details to the story. Note the addition of shading to maps (b), (d), and (e). On maps (d) and (e), OSM trail and road data (which otherwise couldn't be seen) have been added as a layer on top of the maps. Map (e) is a satellite image but becomes a usable map with the addition of trail and road data. Map (f) is the free planimetric map that is handed out when you enter the park:



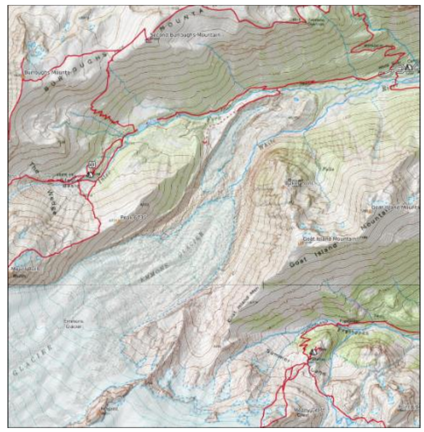
a. commercial printed map



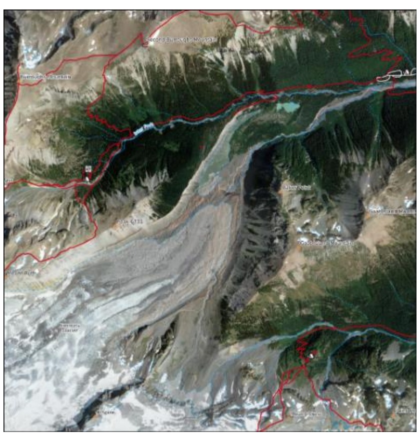
b. commercial digital map



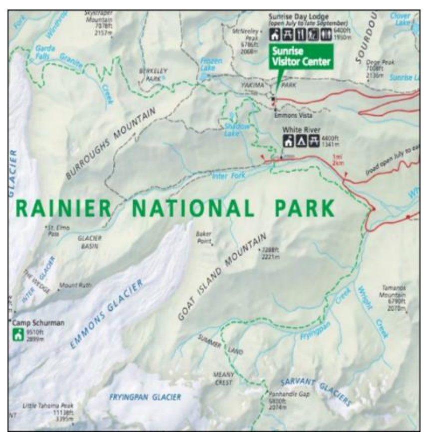
c. USGS paper map



d. Scanned USGS map with overlays



e. satellite image



f. planimetric relief map

Fig. 1-3. Comparison of topographic maps for Mt. Rainier, northeast side: a, commercial printed map (Green Trails); b, commercial digital map (CalTopo); c, USGS printed map; d, scanned USGS paper map with shading and OSM trail overlays added using digital mapping service (CalTopo); e, satellite image with OSM trail overlay added using digital mapping service (CalTopo); f, planimetric relief map using shading. {Use a smaller, simpler zoomed-in area. Less "ink density."}

PHYSICAL MAPS IN A DIGITAL WORLD?

In a world where digital tools dominate, it is easy to overlook the value of physical maps. However, there are compelling reasons why paper maps play a critical role in wilderness navigation, even in the age of cell phones and GPS technology.

First, paper maps offer a macro view of the landscape that can be difficult to achieve with digital tools. Zoomed-out maps provide a broad perspective of the terrain, making them helpful for initial planning, route-finding, and on-the-fly decision-making. When traveling in a group, an unfolded map keeps everyone on the same page about the route and alternatives. This battery-free, non-electronic bit of paper in your pack can increase confidence when navigating challenging conditions.

Research[1] has also shown that paper maps are superior when forming a cognitive map of an area. While digital tools may allow for the quick acquisition of surface knowledge of a region, paper maps enable navigators to put themselves into a regional context.

Paper maps also provide critical information about potential obstacles, natural features, and landmarks that may be hard to find on the diminutive digital screen. They also offer a tactile, tangible experience that enhances the navigator's situational awareness and connection with the environment.

At their core, GPS devices provide coordinates. When you pair that capability with a relevant digital map, the result is easy and accurate navigation. However, there is a rucksack of reasons why you may not have the relevant digital map, or your primary device has a glitch, forcing you to rely on a backup device. Some devices do not have an onboard digital map and yield only coordinates. Nevertheless, raw coordinates, combined with a paper map with grid lines, will show you exactly where you are on the map. We will cover this topic in Chapter 5.

Although digital navigation tools have moved into the lead role, paper maps remain essential to the navigator's toolkit. By using digital and paper maps, navigators can take advantage of the unique strengths of each to ensure they have a comprehensive and reliable navigation system at their disposal.

THE LIMITATIONS OF MAPS

Maps are an abstraction of reality; as such, they have limitations that can impact their accuracy and usefulness. Their ability to show the details of a landscape is restricted by their size and the cartographer's desire to avoid clutter. But note that digital vector-based maps are databases, not

[1] {Footnote reference here.}

drawings. The detail level will increase as you zoom in and decrease as you zoom out. This seemingly limitless increase in detail when zooming is false and is always limited by the details available in the database. Also, zooming out eliminates some details that may be important to your journey; some details are, frustratingly, only visible at certain intermediate zoom levels.

It is important to check the map issue or revision date because the older a map, the more suspect its information becomes. We live in the Anthropocene Epoch, during which human endeavors, including logging, roads, trails, and dams, significantly impact the earth and the accuracy of our maps.

Climbers use the term *beta* to mean data gathered about an area. The more complex and difficult the trip, the more critical it is to supplement any map with beta from alternate map types, guidebooks, websites, local officials, and previous visitors.

CARDINAL DIRECTIONS: NORTH, EAST, SOUTH, WEST

A simple but critical foundational fact is the positional relationship of the four basic "cardinal" directions: north and south, east and west. While many readers have mastered these relationships, many knowledgeable adults still need help with the interplay between the four cardinal directions. Look at Figure 1-4 at right and memorize the relationship of each direction to the others. It's helpful to start with north and proceed to the right (clockwise) around the "compass rose." If it helps, use the children's mnemonic "Never Eat Slimy Worms." Following are three exercises to help crystallize this foundational idea:

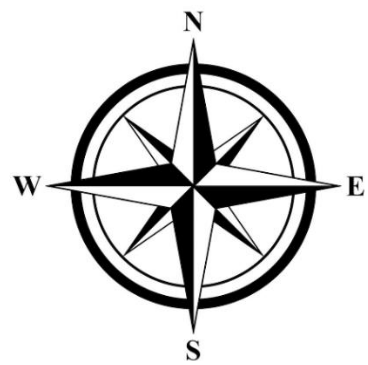


Fig. 1-4. Compass rose showing the cardinal directions.

Exercise 1. You can use a visualization exercise to gain a visceral feel for the cardinal directions. Start by standing up and extending your arms wide, your nose facing north (Figure 1-5). Your right hand points east, your back is turned to the south, and your left hand points west.

If you're in the northern hemisphere[2] (and not too close <u>to</u> the equator), envision the sun's arc throughout the day. Your right hand will greet the sunrise, your right shoulder will be warmed in the late morning, your back at midday, your left shoulder in the evening, and your left

2 If you are in the southern hemisphere (and not too close to the equator), imagine the arc the sun will take throughout the day in front of you, first greeted by your right hand, then warming your right shoulder, your nose at midday, your left shoulder in the evening, and your left hand waving goodbye as it sets. If you are close to the equator, imagine the sun traveling in an arc directly above you, first at your right hand, then your right shoulder, then the top of your head, left shoulder, and then your left hand.

hand will wave goodbye as the sun sets. Your nose remains in shadow.

You are now thinking like a navigator.

Exercise 2. Look again at the maps you downloaded above in the “First Map” section. Even though you are not currently at Mt. Rainier, orient the map north at your current location. Imagine standing at the restroom above the words “Glacier Vista.” Envision a bird’s-eye view of the landscape. What major map features would a hovering hawk see in each cardinal direction?

Fig. 1-5. Visualization exercise for the cardinal directions.

Exercise 3. Figure out where north is from your current location. Practice pointing to the cardinal directions, north, east, south, and west, proceeding clockwise from north. Envision a hawk’s-eye view of your neighborhood. What major roads, buildings, and landscape features would you see 1,000 feet up? How do they relate to each other and the four cardinal directions?

Exercise 4. Many of our cars have a rearview mirror or dashboard compass. When driving, pay attention to your surroundings to estimate your direction of travel and then check it against the compass. Consider where the sun is in its daily journey along the ecliptic. Consider whether your city is on a north-south/east-west grid or some prominent streets or highways run in a particular cardinal direction. Are there landmarks that can help you keep your sense of direction?

I grew up in Seattle, where avenues generally run north-south, and streets typically east-west. Mt. Rainier is southeast, the Cascade Range is east, the Olympic Mountains are west, and the primary freeway, I-5, runs north-south. Seattleites often use cardinal directions when giving directions.

FUNDAMENTALS OF MAP READING

Before embarking on the exciting journey of deciphering topographical maps, we must grasp the fundamental components of a map. This section will delve into the key elements traditionally found in a map's margin, providing a solid foundation for the adventure ahead. Then, we will explore the skills of measuring distances and unraveling the intricate language of contour lines. Understanding these components will lead us toward reading topographic maps, the essential skill that will empower you to navigate untamed terrain confidently.

> **GOOD SENSE OF DIRECTION?**
>
> While scientists are not sure whether some of us are born with an innate sense of direction, we are confident that navigation is a skill that can be learned and improved with practice. Experienced navigators are keen observers of the passing terrain with their eyes and instruments. This book can teach you what to observe and how to use instruments to enhance your "vision" and sense of direction.

MARGIN MATTERS

A map's margin often contains a wealth of information to interpret its dense symbology. The margins of commercial and government maps contain the most complete information. Home-created maps typically contain only critical information. Digital maps have no margin but sometimes have a link to the map's legend. The following are examples of typical margin information:

- **Map issue and revision dates:** Maps typically show their original issue and latest revision dates, which allow you to understand the age of the map's data. The older a map becomes, the more suspect its information. For example, the accuracy of a map's stated declination has slowly degraded since its latest revision. Declination changes over time. This change can be as slow as 1° per 50 years to as rapid as 1° every three years.
- **Scale:** Figure 1-6 shows a sample map scale. This map's scale indicates that any unit chosen to measure the map (centimeter, inch) equals 50,000 times that unit on the ground. This means every inch or centimeter on the map is 50,000 inches (about 0.8 miles) or 50,000 centimeters (500 meters) of walking in the real world. A scale of 1:50 000 to 1:100 000 is best for planning on-trail trips and may be sufficient for executing on-trail trips. More zoomed-in scales of approximately 1:25 000 are better for off-trail travel.
- **Scale of digital vs. physical maps.** One advantage of **modern digital maps** (known as "vector" maps, to be covered later) is the lack of a fixed scale. Instead, the user can zoom in or out to see either more details of a smaller area or fewer details of a larger area, subject to the limitations of the database and the quality level chosen when downloading. The font size also adjusts to be readable at any zoom level. **Physical maps**, of course, can't zoom, but their steady depiction of the landscape at a constant scale helps the user grasp distances and spatial relationships. Home-created maps can be printed at a wide range of scales. Together, digital and physical maps make a talented team. Note in Figure 1-6 below the three methods used to communicate scale—ratio, verbal, and bar:

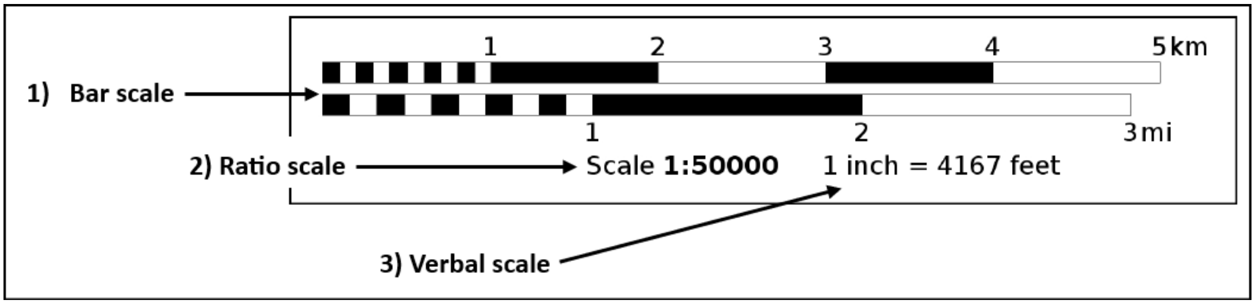


Fig. 1-6. (1) Bar scale, (2) Ratio scale, and Verbal scale.

A map's scale is fundamental in determining whether it will be helpful for a particular activity, such as driving to the trailhead, trail planning at a high level, or planning an off-trail route. Table 1-3 is an overview with examples of zoomed-in and zoomed-out scale maps and their best uses:

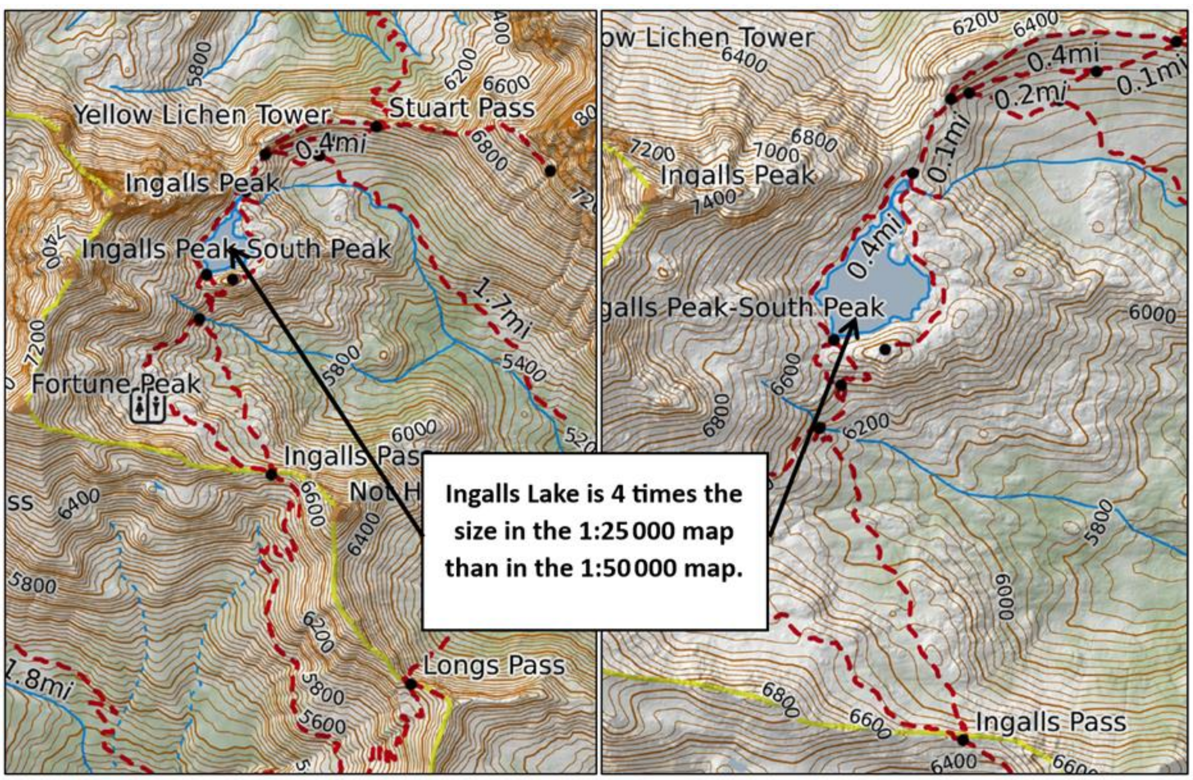
TABLE 1-2. MAP SCALE GUIDE

	COMMON SCALES	1 INCH (1 CM) EQUALS	TYPICAL CONTOUR INTERVAL	EXAMPLE MAPS	BEST USES
<<<<Zoomed in / Zoomed out>>>> <<<<(Large scale) / (Small scale)>>>>	1:1 000 000+	15.8 mi (10 km)	None	State or country	Driving
	1:200 000	3.2 mi (2 km)	300 ft (90 m)	DeLorme Gazetteer, road atlases	Backroad driving, very high-level trail planning
	1:100 000	1.6 mi (1 km)	100 ft (30 m)	Certain USGS, National Geographic Trails Illustrated	High-level planning
	1:50 000	0.8 mi (.50 km)	80 ft (24 m)	NATO, Commercial backcountry	trail planning
	1:25 000[3]	2000 ft (.25 km)	40 ft (12 m)	USGS Quad, UK OS	Detailed trail or off-trail planning

- **Small-scale vs. large-scale.** The terms "small-scale map" and "large-scale map" are counterintuitive and often confused. Detailed maps of smaller areas (a park, for example)

3 1:24 000 is a common US scale used by the USGS for their standard "US Quad" maps of the United States. These can be treated as equivalent to 1:25 000, with a mere 4% difference.

are described as *large-scale maps*, and maps of larger areas (a state or country, for example) as *small-scale maps.* The cartographers' persistent use of these confusing terms is occasionally unavoidable, and I have used the more helpful terms "zoomed in" and "zoomed out" for the rest of this book. Figure 1-7 shows two maps of Lake Ingalls and Ingalls Peak at different scales. Map A is scaled down to be 1/50 000th the original size. Map B is scaled down to a lesser degree, to 1/25 000th the original size. Map A is more zoomed out, so the lake, peak, and surrounding features will be smaller on the map. Map A is, therefore, a "smaller scale" than Map B and shows a larger area. Map B is more zoomed in, so its lake, peak, and surrounding features will be larger. Map B, therefore, has a larger scale than Map A but shows a smaller area. Ingalls Lake on Map A will be half the width and height and, thus, one-fourth the size shown on Map B. Note that whether a map is zoomed in or out is subjective. Hikers view a 1:100 000 scale as zoomed out and only appropriate for high-level planning, while pilots view such scale as unworkably zoomed in and prefer 1:500 000.



Map A
Zoomed-Out Map
1:50 000
("Small-Scale" Map)

Map B
Zoomed-In Map
1:25 000
("Large-Scale" Map)

Fig. 1-7. Map scale comparison of zoomed-out map vs. zoomed-in map.

- **Contour interval.** Contour lines mark points of equal elevation on a map. The contour interval is the real-world elevation difference between contour lines. Typically, every fifth contour line is an *index contour* and is shown darker with the elevation indicated. Figure 1-8 states the contour interval, shows an index contour, and a spot summit elevation.

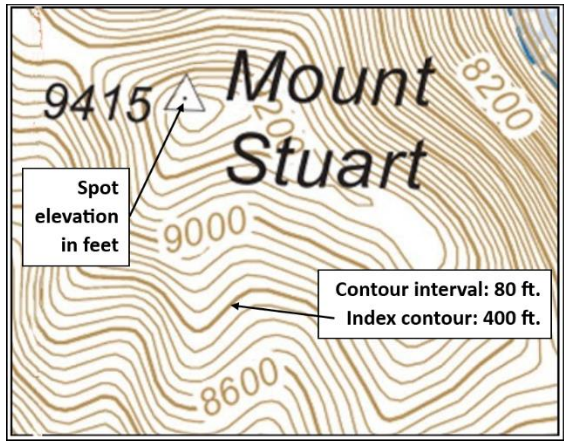


Fig. 1-8. Contour interval example.

A map's choice of contour interval can trick the eye by affecting the perceived steepness of the landscape. One time, on a hike in Strathcona Provincial Park in Canada, I was fooled by the larger contour interval of the Canadian metric map into thinking a route would be easier than it turned out to be. We didn't make the summit, but my hiking partners forgave me. As noted above, maps are imperfect approximations of the real world. Contour lines often fail to communicate challenges in the topography, such as impassible gullies and cliffs. Such challenges can appear without warning from the map, even when they are much larger than a map's contour interval.

The two map sections in Figure 1-9 cover the Mountaineer's Route to The Notch on the way to the summit of Mount Whitney. The map on the left uses a 40-foot contour interval. The map on the right uses a 10-foot contour interval, making the slope appear much steeper:

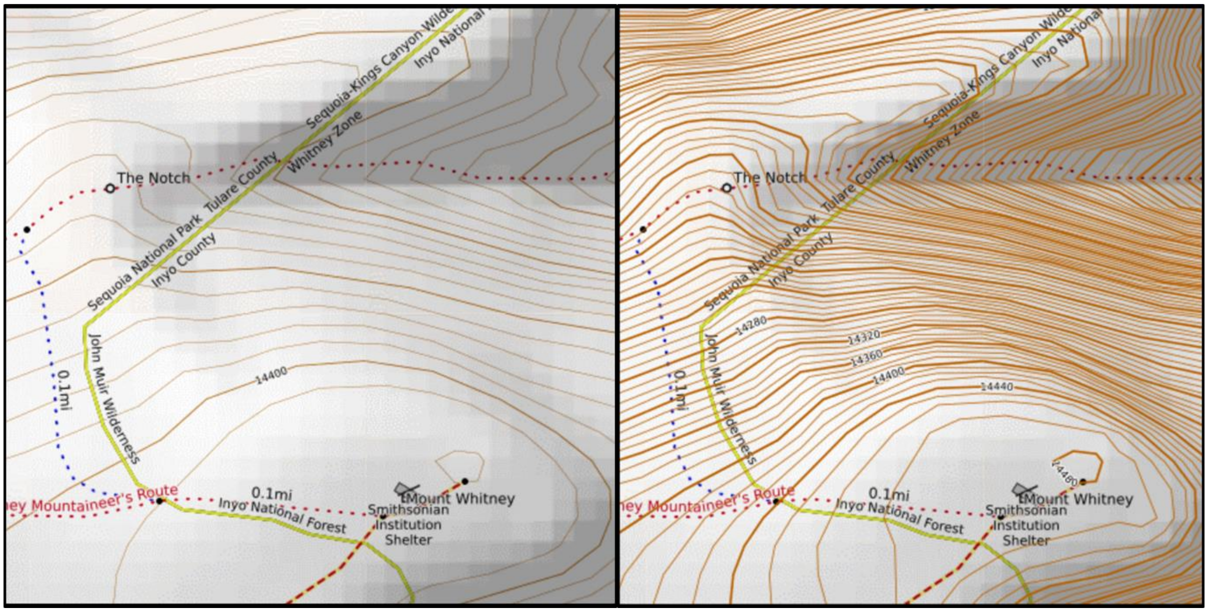


Fig. 1-9. Alternate contour intervals. [FINAL MAP: delete Inyo county border. Show the mountaineer's route more clearly; reprint using 400 DPI.]

- **Declination.** In Chapter 3, we will present the compass. The magnetic field has a well-defined direction at every point on the earth. Subject to error from other magnets and many metals, the magnetic needle on your compass will reliably align itself with the direction of this magnetic field, which is only occasionally the same direction as true north. Declination is the angle between true north and magnetic north as determined by the local magnetic field. Because declination varies over time, driven by changes in the Earth's internal geology, most maps indicate the declination in degrees as of the map's issue or revision date.

  As noted above, the accuracy of the map's stated declination degrades over time. This degradation can be as slow as 1° per 50 years to as rapid as 1° every three years. Therefore, older maps do not accurately reflect current declination values. To ensure precision, check the declination on the map with an online tool (e.g., magnetic-declination.com) or phone app. Specific declination apps will give this data anywhere on a world map. Some compass apps will give local declination. "Magnetic variation" or "magnetic declination" are the terms preferred by mariners and pilots to differentiate it from the term "declination," which has a different meaning in astronomy and celestial navigation.

- **Declination diagram.** The current declination in any location is used to set up declination-adjustable compasses or to make the necessary math computations. Most maps include a declination diagram, like the example below, which displays the local declination in degrees and shows whether compasses in that location will point too far east of true north (clockwise, as in the diagram below) or west of true north (counterclockwise). Chapter 3 will delve into declination in more detail, including other ways to determine local declination. Some diagrams also depict "grid north" because a UTM grid can deviate up to 2 degrees from true north. With a latitude and longitude grid, latitude lines always run east-west, and longitude lines always run north-south. Declination diagrams frequently have a star representing true north and a statement of the current annual rate of change of magnetic north to help estimate declination at future dates.

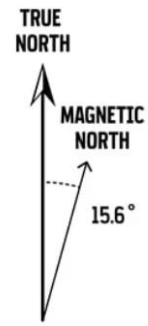


Fig. 1-10. Typical declination diagram showing true north and magnetic north on the map as of its publishing date.

- **Legend symbols.** Each map publisher uses a unique set of symbols to represent geographic data, such as roads and trails, boundaries, campgrounds, buildings, power lines, streams, waterfalls, and wetlands. A map legend shows examples of the map's symbols and their unique meaning for that map type.
- **Map colors.** Cartographers also choose map colors to convey information. Some colors are standard to most maps: blue represents water features (lakes, rivers, streams, and oceans); green represents vegetation (darker green indicates denser vegetation); white or tan represents minimal vegetation, desert, rocky areas, glaciers, and mountain peaks; brown represents contour lines and elevations (except on glaciers where they are blue); and black represents human-made and cultural features (e.g., place names, buildings, railroad tracks, roads); red typically represents highways and major roads. Other color choices will vary by publisher.
- **Datum:** The fine print of a map's margins typically states the horizontal (and occasionally vertical) datum used to anchor the map and its related grid lines to the earth. This topic is covered with GPS in Chapter 5.
- **Grid lines.** The grid lines on a map are a system to identify x-y coordinates. There are several systems for coordinates, the most common being the latitude and longitude system and the UTM system. Grid lines are necessary to connect the world of physical maps to the world of GPS. This topic is covered with GPS in Chapter 5.

MEASURING DISTANCES: "ARE WE THERE YET?"

Knowing the distance to your objective is critical to estimating travel time when combined with the terrain and elevation change. You can measure straight-line distances on a map with the ruler on the side of your compass, but the typically winding way ahead is most easily measured using a digital map. If you create a route—a series of waypoints toward your objective—your GPS app will determine the distance and elevation change. This is covered in Part II: Low-Visibility Navigation by Instrument. Alternatively, you can lay a thin piece of cord, such as the lanyard on your compass, on your planned route on your physical map. Next, measure the cord against the map's bar scale. A twig cut to a convenient distance, such as 1 km on the bar scale, can be used to estimate distance. Your thumb's width may also be a convenient measure for thumb-walking your planned route. For example, my thumb's width is about 2,000 feet on the bar chart of a 1:25 000 map and about 0.75 miles on the bar chart of a 1:50 000 map.

UNDERSTANDING CONTOUR LINES

The mapmakers' conundrum was how to represent the undulating earth on a flat map in a helpful way. Contour lines solve the problem as imaginary lines that connect points of equal elevation. Picture walking around the base of Rose Mountain in Figure 1-11(a) below at precisely 1,000 feet[4] with a giant paintbrush marking this elevation as you walk, without gaining or losing elevation, eventually returning to your starting point. That would be a single contour line. Then imagine ascending a fixed amount vertically, say 40 feet of elevation. You then repeat your herculean task, circumnavigating the mountain at 1,040 feet. Again, you would return to your starting point, having completed your second contour line, never having crossed your first.

You repeat the task, ascending 40 feet of elevation each time and painting each fifth line darker. Where the land is steeper, you would need to climb up steeply with only a small change in your position horizontally. Where the land is flatter, you would walk some distance before you gain 40 feet of elevation. When your labor is complete, it will appear, viewed from the side, as below [Figure 1-11(b)]. The contours would be evenly spaced like giant bathtub rings, each perfectly level but conforming to the irregularities in the landscape. But, from a bird's-eye view [Figure 1-11(c)], steep areas show the lines close together, and flatter areas show them spaced farther apart. This is a topographical map, the mapmakers' clever solution to the conundrum. With sufficient imagination, we can translate the mapmaker's swirly map contours into a landscape with elevations.

[4] Since this merely a thought experiment, "feet" are without conversion.

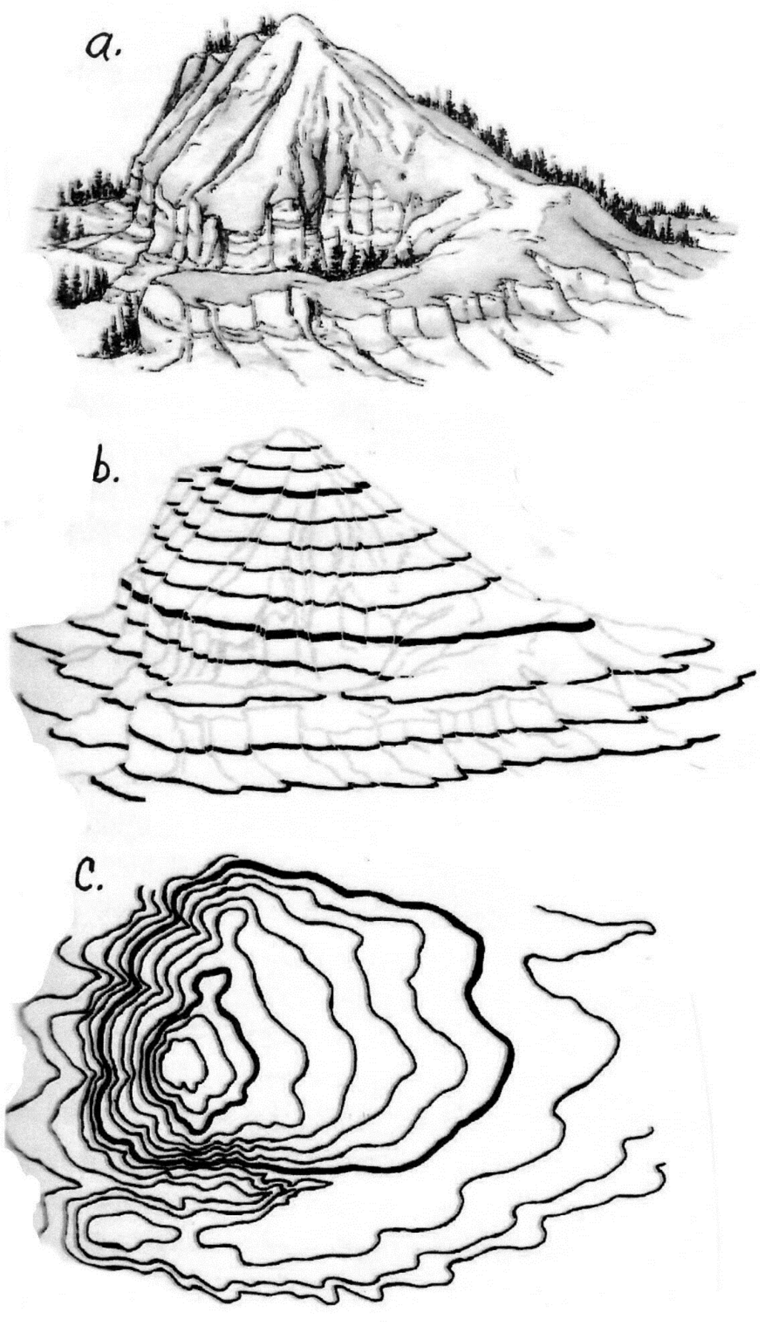


Fig. 1-11. Creating contour lines on Rose Mountain: (a), side view of the mountain peak; (b), side view with topographical lines; (c), top view of the mountain peak's contour lines transferred to a map. *[On the contour map (c), add one regular contour at mtn base; Add one darker "key contour" below the previous contour; Add labels to the three darker key contours (as in the example below): "1000" to the lowest one, "1200" to the next, and "1400" to the smallest one near the summit; add an "x", summit elevation of "1511", and name: "Rose Mountain."]*

MAP PRACTICE

Most of my backcountry errors start with not reading the map with sufficient care. Concentration and time are required to tap into the vast information they contain. Now that you have spent some pages thinking about the parts of a map, again review the maps of Mount Rainier National Park that you downloaded above. See if you can answer these questions:

1. What is the scale of each of these maps? Which map is more zoomed-in?
2. What are the contour and index contour intervals for the 1:25000 map?
3. What is the declination for these maps? Do compasses in this region point too far east (clockwise) or west (counterclockwise)?
4. Is a climbing route from Camp Muir to the summit of Mount Rainier noted?
5. Do both maps have grid lines?
6. What is the highest point on each map? Estimate this height based on the contour lines.
7. For the 1:25000 scale map, what is the lowest labeled index contour line? What is the approximate elevation of Camp Muir? What is the difference in elevation between Camp Muir and Paradise?

Answers:

1. 1:50000 and 1:25000 (or 1 inch = 4,167 feet and 1 inch = 2,083 feet). The 1:25000 map is more zoomed-in.
2. The contour interval is 40 feet, and the index contour interval is 200 feet.
3. 15.0° east. Compasses in this region point too far east (clockwise).
4. Yes, as a dotted blue line.
5. Yes, both maps have grid lines for identifying x-y coordinates. Grid lines are necessary to connect the world of physical maps to the world of GPS. They are covered in depth in Chapter 5.
6. The highest point on both maps is the summit of Mt. Rainier. A small closed, unlabeled index contour at 14,400 feet is indicated.
7. The lowest point is the southwest corner along the Nisqually River, with a labeled index contour line of 3,800 feet. The elevation of Camp Muir is approximately 10,000 feet. The elevation difference between Paradise at about 5400 feet and Camp Muir is approximately 4,600 feet.

READING TOPOGRAPHIC MAPS

Understanding how to read topographic maps is an essential skill for wilderness navigators. Topographic maps provide detailed information about the terrain, including elevation, slope, and landforms. This information can help us plan our routes to stay safe and enjoy the wilderness. In this section, we will explore the critical features of topographic maps and how to interpret them effectively.

Until map reading becomes second nature, following these two steps will allow you to translate the map's lines and symbols for navigation:

- **Step 1: What's up?** Determine which areas of the map are high ground and which are lower by looking at key geological features.
- **Step 2: Significant LOPs.** Identifying significant lines of position is a major topic of the rest of this book. This section will introduce the topic, followed by a deeper dive in Chapter 2.

Step 1: What's up? Moving from one contour line to its neighbors means going uphill or down. If you were doing neither, you would be strolling along the contour line at a constant elevation. So, how do we know if we're going uphill or down? In the landscape, it's obvious, but understanding this concept on a topographical map requires some thought. Three geological features will quickly give you the lay of the land: watercourses, peaks, and slope. With this orientation, the other major landforms will be easy to identify.

1. Watercourses. Start with the watercourses in the area because water reliably flows downhill. Closely examine the map's streams and lakes. From there, identify the gullies or valleys where streams always flow and basins where lakes always sit.

Streams. A quick way to determine high land from low is to use the rivers, streams, creeks, and brooks (indicated on the map in blue) and their interactions with contour lines. Pick a stream and determine which direction it flows by closely examining adjacent contour lines. Knowing that water flows downhill, you can follow this stream until it disappears into a body of water or leaves your map. Then, follow the stream uphill again until it disappears into a body of water, arrives at its headwaters, or leaves your map. This is the beginning of understanding up from down.

Confluence. When two streams merge, they typically form a Y shape—the two arms of the Y point toward the upstream flow, indicating higher ground. The base of the Y points downstream, indicating lower elevation terrain. See Figure 1-13(e) (near the bottom of the map) and Figure 1 13(h), where the blue upside-down Y shape indicates higher ground toward the bottom of the map. See Figure 1-13(e) for a more ambiguous example.

Water-related features: gullies, ridges, lakes, saddles, and cirques.

Gullies. Streams, of course, flow downhill and do so in troughs or channels such as gullies, ravines, couloirs, canyons, gorges, or valleys formed by slope erosion. They *never* flow on ridges. Gullies (and ravines, etc.) and ridges can be easily confused with each other, but if there is water in it, it is not a ridge! Furthermore, Figure 1-13(b) shows how the contour lines in the gully form V shapes where the arms of the V point downhill and the tip points uphill. They point to higher elevations, not necessarily *up the map*, where the top merely means north. This figure's contour lines are pointed like a V or an arrow, but those on your map may instead be a rounded U shape. Now that you know how to recognize gullies (and the like) with water, remember that such structures may be dry, although they were likely formed by water erosion. **Valleys** are elongated low areas between mountains or hills, frequently containing a stream or river. On a topographic map, valleys are represented by contour lines that form V or U shapes pointing toward higher elevations, as in Figure 1-13(e).

RAVINE VS. RIDGE REMINDER

Remember that water only flows in low areas such as gullies, ravines, or couloirs. Search a slope for a stream, and you will notice that the V- or U-shaped contours in which it flows point uphill. Conversely, contour lines that form V or U shapes and point downhill indicate an elevated land feature such as a ridge. Review the sample map snippet of a gully and ridge in Figure 1-13(b) and (c).

Ridges are long, narrow, elevated land features. The contour lines that form ridges are V- or U-shaped but point downhill to lower elevations rather than uphill. See Figure 1-13(c) below. When standing on the centerline of a ridge, there will typically be lower elevations in three directions and a higher elevation in one direction, as in Figure 1-13(c). **Spurs** are minor ridges extending from more prominent ridges. **Aretes** are narrow mountain ridges, particularly when formed by glacial erosion on both sides.

Lakes. The water that forms lakes accumulates in basins, which are depressions or low-lying areas in the landscape. Basins are the lowest points in the immediate terrain, and the closed contour lines that encircle and define lakes increase in elevation as they move away from the lake. Closely examine the slope of the land surrounding a lake. Typically, the terrain will slope upward as you move away from the lake, indicating higher ground.

Saddles are broad, relatively low points along a ridge or between two peaks, mountains, or hills. They slope up in two opposite directions along the ridge and slope down in the other two. The contours of a saddle will show a series of V or U shapes pointing downhill toward the saddle's low point and along the axis of the ridge. **Cols** (also known as **gaps**) are more sharply defined and are associated with aretes. **Notches** are exceptionally rugged cols. **Passes** are navigable routes between hills or mountains, or over ridges, which use saddles, cols, or notches. See Figure 1-13(a).

Cirques are amphitheater-like or bowl-shaped valleys formed by glacial erosion. A cirque is also known as a coombe, combe, or cwm, the latter being especially useful for playing Scrabble. See Figure 1-13(d).

2. Peaks, mountains, and hills have ground that slopes down in all directions, indicated by roughly concentric circles or other shapes that decrease in size as they ascend. The corresponding **summits, pinnacles, and hilltops** are within the smallest and highest closed circle or shape, occasionally indicated by an X, a triangle, or an elevation, as in Figure 1-13(a). Look at Caltech Peak in Figure 1-12 below (or download from the QR code or URL below) for a larger view. We know this is a peak not just because it is labeled "peak" but because of the contours of increasing elevation that end with a closed contour at the summit. There is no further uphill travel from the last small, closed contour. Observe how the elevations on the nearby index contours increase toward the summit. Directions that go straight uphill or straight downhill (the "fall line") run perpendicular (at right angles) to the contour lines. Observe how the three black arrows run perpendicular to the contour lines, each pointing directly downhill. Similarly, note how the two black arrows near Forester Pass run downhill. (Incidentally, at 13,180 feet (4,017 m), this is the highest point on the Pacific Crest Trail.)

Related features: slope and depressions.

The slope is the side of a hill or mountain. Cliffs have contours bunched closely together or overlapping, forming a brown mass. For example, see the northwest and northeast faces of Pinnacle Peak [Figure 1-13(a)] and the north side of Jagged Ridge [at the bottom of Figure 1-13(d)]. Figures 1-13(f) and (g) show a ridge top extending south from Peak 3852. To the west of the ridge are steep slopes. To the east of the ridge are moderate slopes. Figure 1-13(h) shows a nearly flat area with few or widely-spaced contours.

Depressions are also indicated by roughly concentric circles or other shapes that decrease in size as they descend. Some maps use hash marks on the downhill side of the contours to indicate a depression.

Step 2: Identify significant lines of position. Lines of position (LOPs) are straightish linear features we can use to navigate. Physical LOPs are tangible features we can see in the landscape and identify on our map. Instrument LOPs require a measurement with a navigation tool (compass, altimeter, or GPS) and then can be plotted or found on our map (bearings, elevations, or coordinates).

Physical LOPs, which can serve as guides, include ridges, valleys, trails, roads, railroad tracks, power lines, tree lines, ridges, gullies, valleys, rivers, streams, shorelines, or any long, narrow feature of the landscape that we can recognize both in the landscape and on the map.

Identifying significant lines of position is a major topic of the rest of this book. Chapter 2 is a deep dive into physical lines of position. Instrument LOPs are covered in Part II: Low-Visibility Navigation by Instrument.

Reading Topographic Maps: Practice

Here are a few exercises to put what you have read above into practice.

What's up? For each of the lines pointing away from points A, B, C, and D, determine whether they are pointing uphill, downhill, or level, starting at the top and working clockwise:

REVIEWER'S COMMENT: Johngo 6283: This is an interesting exercise. It's a little long, because there's 16 different answers, and a little confusing, because you've got a couple of unlabeled diagrams on the map they don't have letters on them. Maybe we simplify this, with perhaps one point with for directions marked initially? I can see this being pretty confusing and intimidating to new people and having folks just skip over it and get frustrated.

McClure: John, thanks for the perspective. I think we should start with an easy example, and then a harder one. I'm going to preserve this comment for future action due to time.

CalTopo.com/p/UU2FH

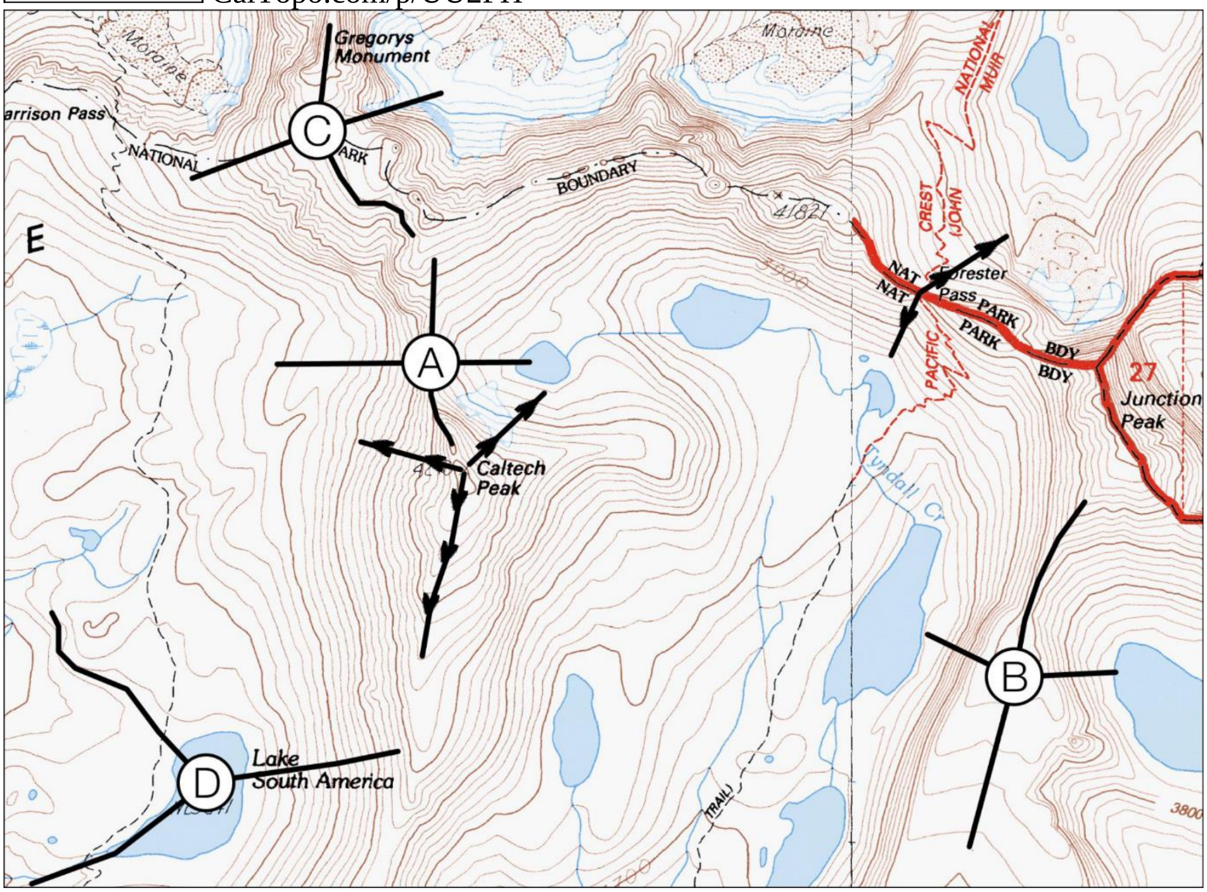


Fig. 1-12. Uphill vs. level vs. downhill.

[Final map: remove Nat Park boundary; show a map with many more labeled index contours as below; avoid a mix of metric and feet]

[Answers, starting at 12:00 and proceeding clockwise: A—up, down, up, down; B—up, down, down, down; C—up, down, neither (it points along the contour), down; D—up, down, neither (it points along the contour), up, down.]

Physical LOPs. Again, review the maps of Mount Rainier National Park you downloaded above. See how many of these physical LOPs you can find:

1. Trails
2. Roads
3. Ridges
4. Glaciers
5. Valleys
6. Rivers or streams
7. Gullies

LOP Questions:

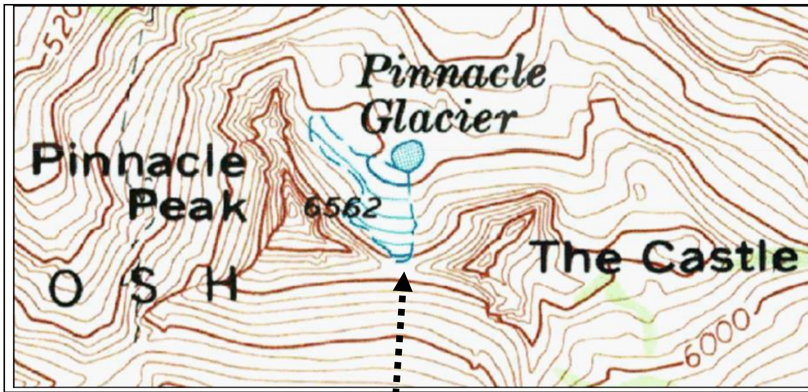
A) Are the dotted blue lines showing climbing routes on the glaciers LOPs?
B) Are the grid lines or contour lines LOPs?
C) Are mountain peaks such as Little Tahoma or Goat Island Mountain LOPs?

Answers:

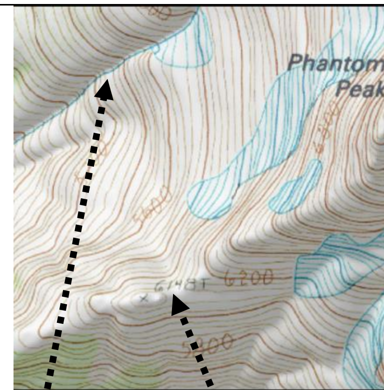
A) No. These are not visible in the landscape
B) Yes, but they are not physical LOPs because they cannot be seen in the landscape. They would require a GPS or an altimeter. (See Chapters 4 and 5.)
C) No. But with a compass, a bearing to the mountains could be measured and then transferred to the map. This bearing would be a helpful line of position. (See Chapter 3.)

EXAMPLES OF THE MAJOR LANDFORMS

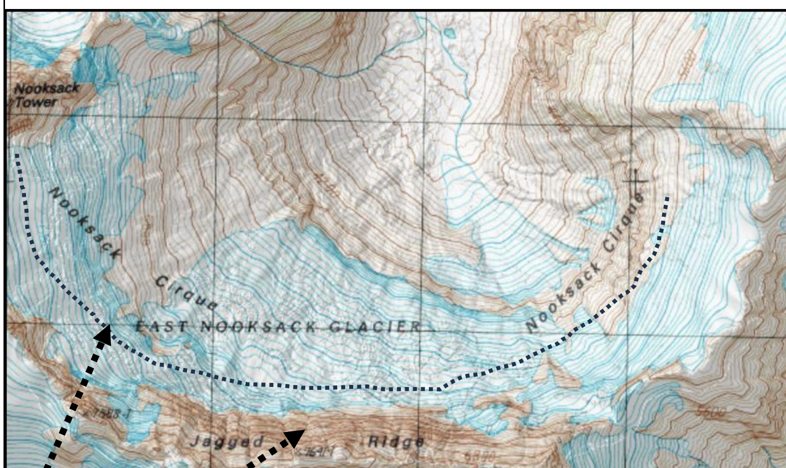
Contour lines on a map describe the shape, size, and height of landforms. By interpreting these lines, you can visualize the landforms in the area, such as peaks, valleys, ridges, ravines, and passes. Closer contour lines mean a steeper slope, while broader spacing means flatter terrain. This spacing allows us to differentiate between flat, moderate, or cliffy areas. We can anticipate an area's topography by analyzing the contour lines and plan our route accordingly. The examples in Figure 1-13 below will help us interpret contour lines to envision different landforms.



a) saddle or col between two peaks

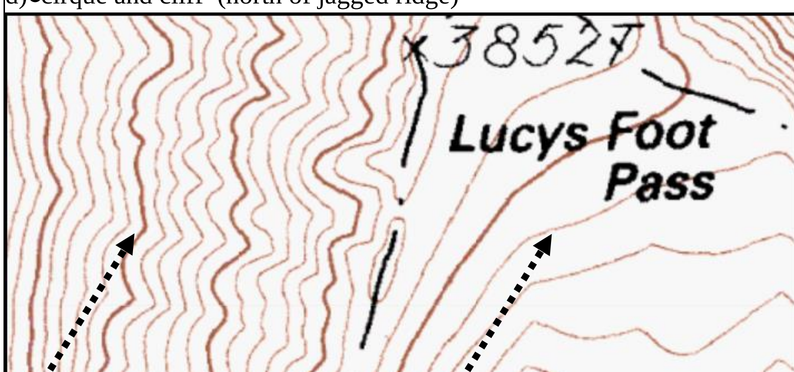


b) gully, ravine, or couloir[1] (upper left-hand corner); c) ridge or spur[1] (lower)



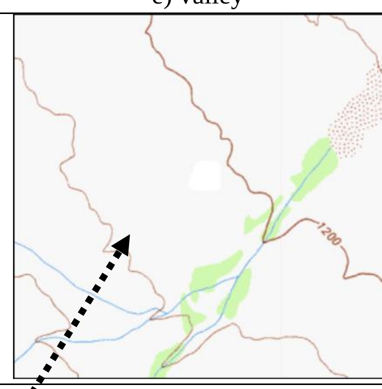
d) cirque and cliff (north of jagged ridge)[1]

e) valley[1]



f) steep slope[2] (left)

g) moderate slope[2] (right)



h) nearly flat area[2]

1. Shading was added for clarity.
2. Contour intervals are the same in maps (f), (g), and (h) to allow for comparison.

Fig. 1-13. Contour line examples showing major landforms.

[Add elevations to all key contours on f/g. Label each feature on each map. Consider line drawings]

MAP PRACTICE

The next time you are relaxing where the view is grand, look at your map and try to imagine the landforms described by the sometimes crazy map contours. Then, try correlating your imagining with what you see in the landscape. This practice is endlessly educational and entertaining. Review these photographs with their corresponding maps in Figures 1-14 and 1-15 to prepare for your first wilderness excursion. The answers are in Figures 1-16 and 1-17.

CHALLENGE #1, MT. TYNDALL

In this challenge, you can practice correlating the contour lines on a map with what you would see in the field. Here, you will find ten points labeled in Figure 1-14(a), the topographical map that corresponds to unlabeled points on (b) the photograph, and (c) the 3-D topographical map. Standing at Point (1), you would be looking at Mt. Tyndall, one of California's 15 peaks that rise above 14,000 feet (4,267 m). Note that (a) the topographical map and (c) the 3-D topographical map are rotated to align with the camera's field of view in (b) the photograph.

Points 1 through 10:

1. Photo taken from here.
2. Two mountains or peaks (Mt. Tyndall on the right; Mt. Versteeg on the left).
3. Saddle or col.
4. Steep slopes (there are many).
5. Moderate slopes (there are many).
6. Cliffs (there are many).
7. Ridges (there are many).
8. Minor summits on the ridge (there are many).
9. Flat area (there are many).
10. Mountain tarn (the other two tarns are hidden).

For challenge #1 below, make a copy of Figure 1-14 and do the following:

Step 1. The photograph was taken from Point (1) on the map. Draw the camera's field of view on the map with two straight lines forming a V with the letter's pointed end at Point (1).

Step 2. Find and label the point on the 3-D map corresponding to each Point (2) through (10) on the topographic map.

Step 3. Find and label the geographic structure in the photograph corresponding to each Point (2) through (10) on the topographic map.

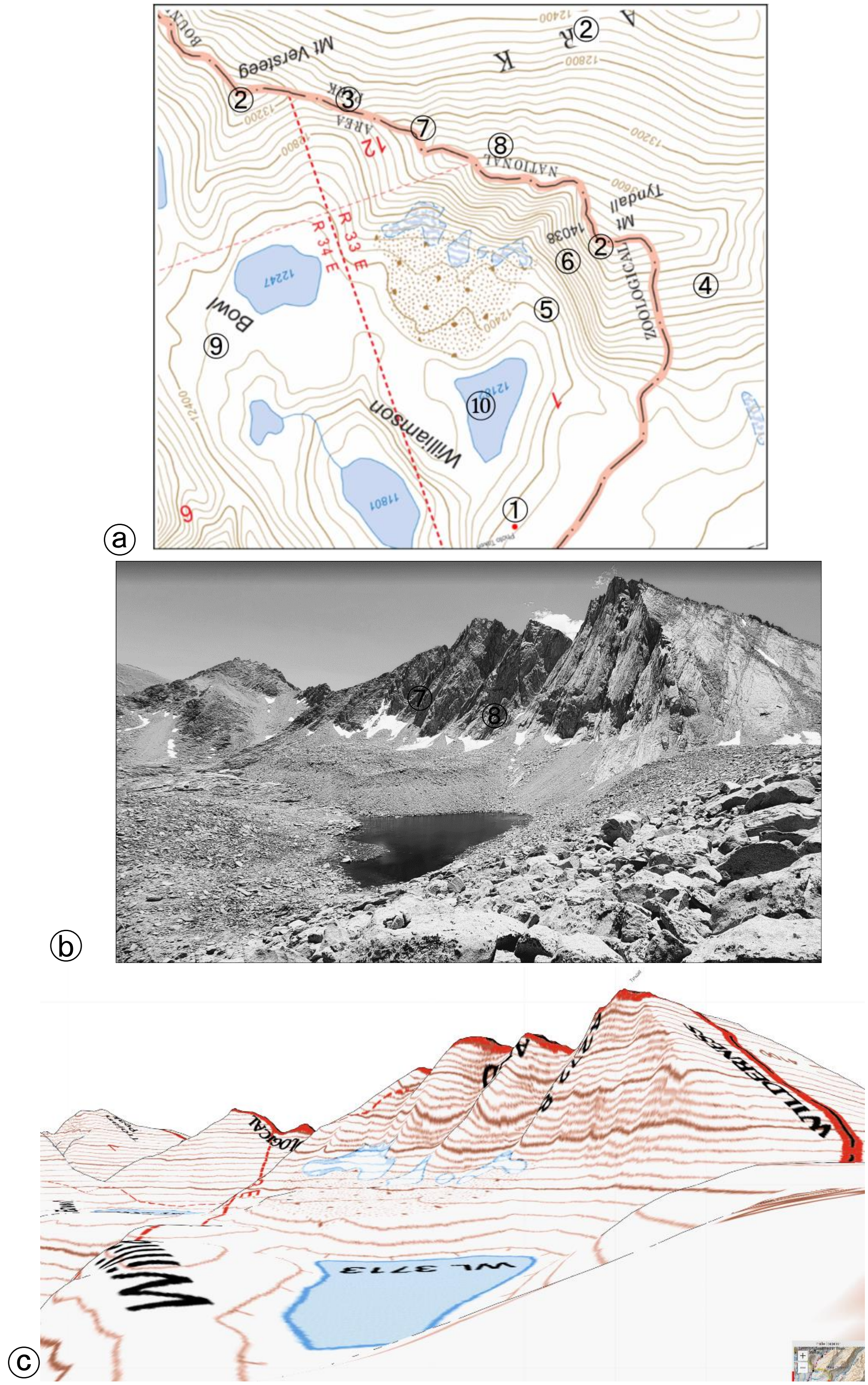


Fig. 1-14. Challenge #1, Mt. Tyndall: a, Rotated topographical map of the area covered by photograph. Arrows show the photograph's angle of view; b. Photograph taken from Point 1 (WGS84 11S 381119E 4058347N); c. Rotated 3-D topographical map of the area covered by the photograph. Photograph by Steve McClure. *[REVIEWER'S COMMENT: Johngo 6283: This last example of the rotated 3-D map looks like it's from some software from 20 years ago. Suggest using a screen grab from FatMap or Google Earth to show modern tools, and to show all of the different lakes. McClure: Good idea. This is from Gaia GPS. I'll take a look at how GE or FatMap looks.]*

CHALLENGE #2, MT. HITCHCOCK

In this challenge, we will again practice correlating what you see on your map with what you would see in the field. Here, you will find nine points labeled in Figure 1-15(a), the topographical map that corresponds to unlabeled points in Figure 1-15(b), the photograph. Point (1) is on the John Muir Trail on the eastern flank of Mt. Whitney, which, at 14,505 feet (4,421 m), is the tallest mountain in the contiguous United States. Looking southwest from this point, you would be looking at Mt. Hitchcock, standing at 13,186 feet (4,019 m). Note the map below is not rotated to align with the camera's field of view. This makes correlating the map and the field view more difficult.

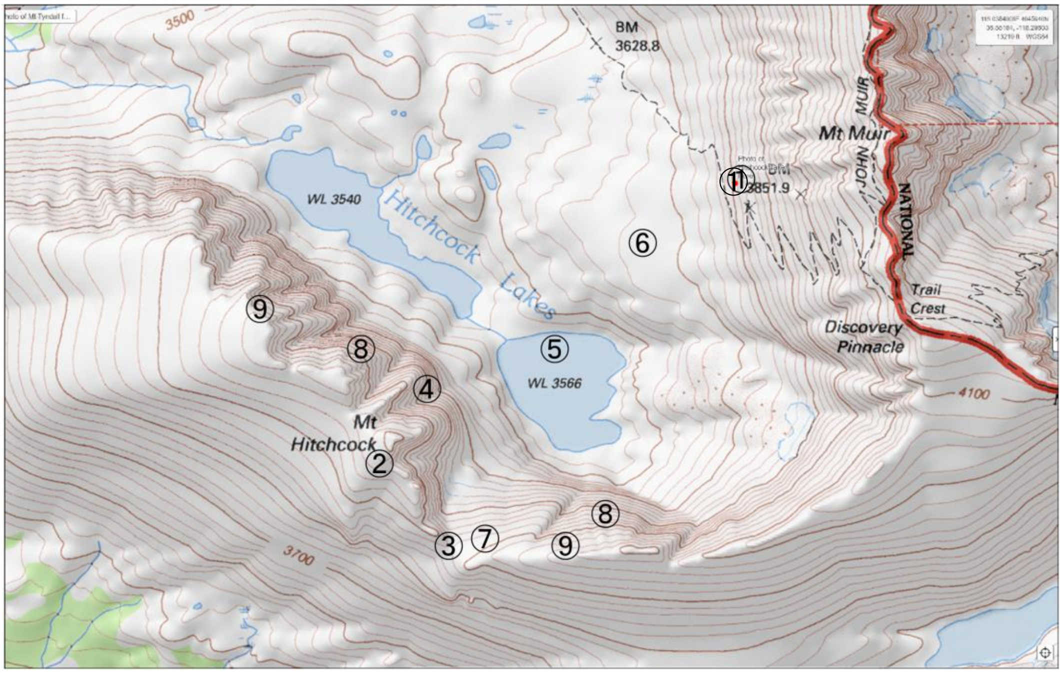
Points 1 through 9:

1. Photo taken from here.
2. Peak (Mt. Hitchcock).
3. Saddle or col southeast of Mt. Hitchcock.
4. Gullies or couloirs (there are many).
5. Mountain lakes or tarns.
6. Flat area (there are many).
7. Moderate slopes (there are many).
8. Cliffs (there are many).
9. Ridges.

For challenge #2 below, make a copy of Figure 1-15 and do the following:

Step 1. The photograph was taken from Point (1) on the map. Draw the camera's field of view on the map with two straight lines forming a V with the letter's pointed end at Point (1).

Step 2. Find and label the geographic structure in the photograph corresponding to each Point (2) through (9) on the topographic map.



ⓐ

ⓑ

Fig. 1-15. Challenge #2, Mt. Hitchcock: a, north-up, non-rotated topographical map of the area covered by photograph. Arrows show the photograph's angle of view.; b. Photograph was taken from Point 1 (WGS84 11S 0383846E 4047196N or 36.56314, -118.29803) Photograph by Steve McClure.

CHALLENGE ANSWERS:

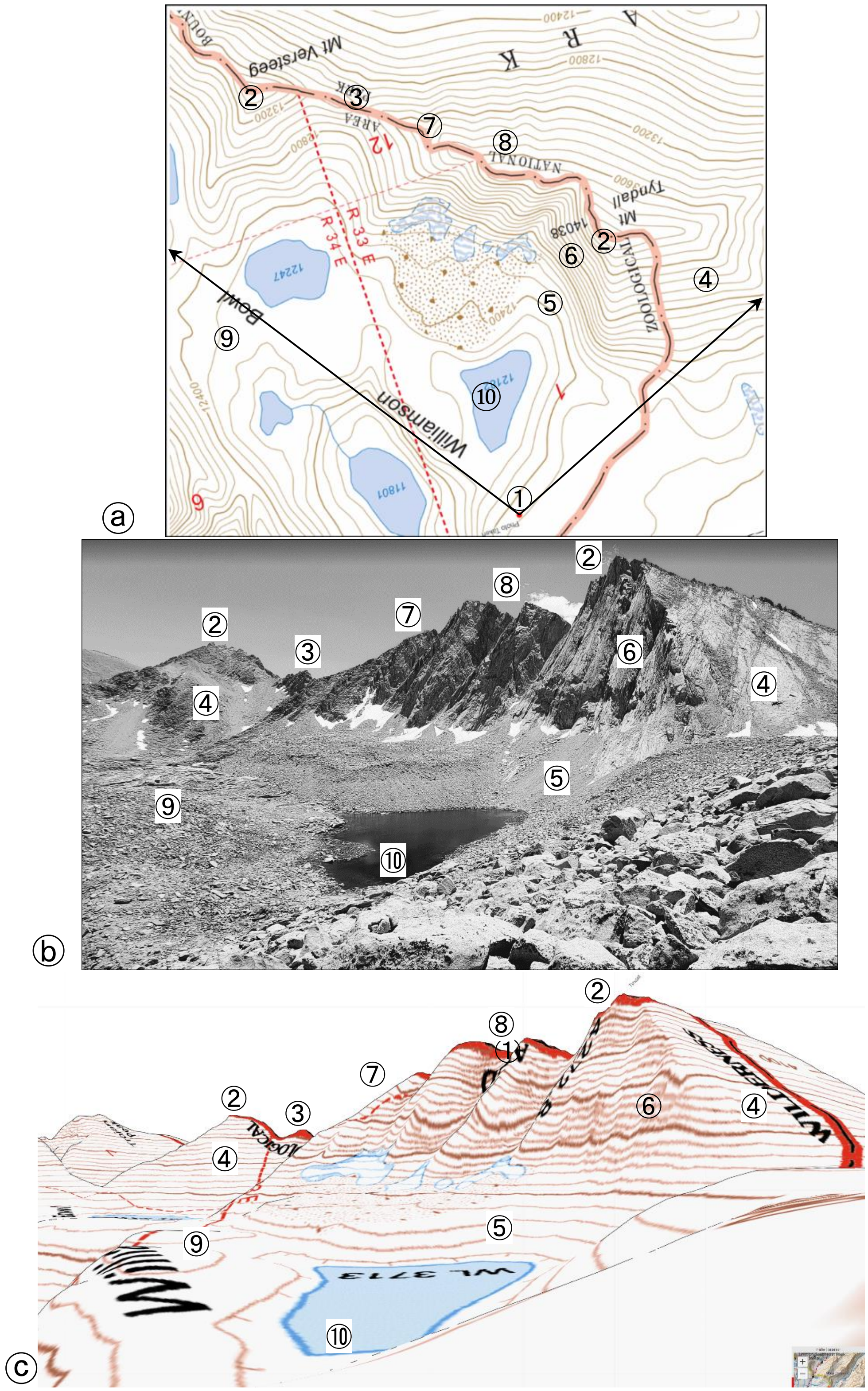
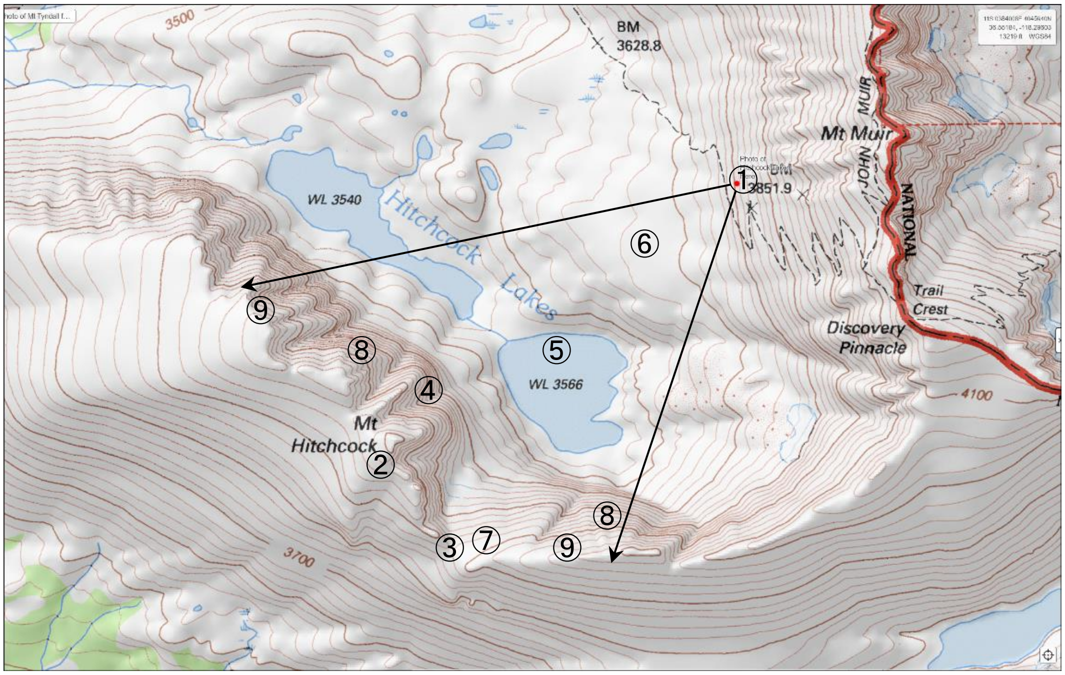


Fig. 1-16. Challenge #1, Mt. Tyndall, Answers, Mt. Tyndall: a, Photograph taken at Point 1; b. Rotated topographical map of the area covered by photograph; c. Rotated 3-D topographical map of the area covered by the photograph.

ⓐ



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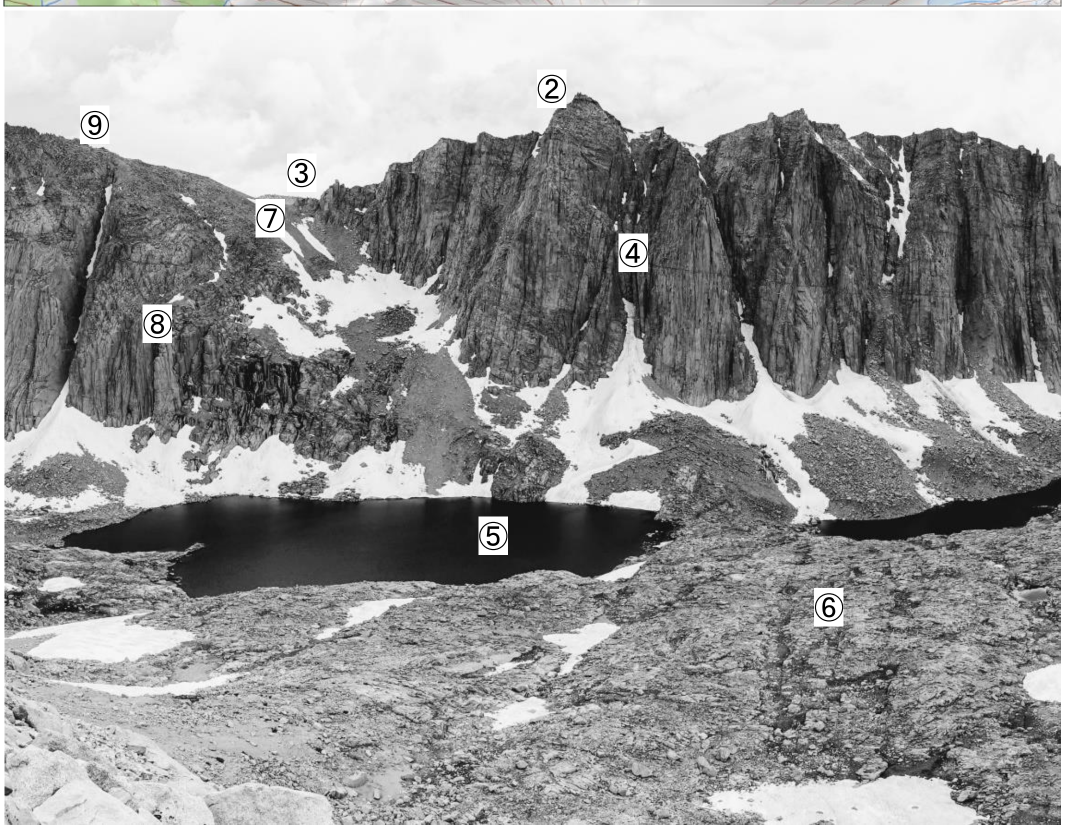


Fig. 1-17. Challenge #2, Mt. Hitchcock, Answers: a, Photograph was taken at Point 1; b. North up, non-rotated topographical map of the area covered by photograph.

Chapter 1 Conclusion

This chapter laid the groundwork for wilderness navigation by introducing the fundamentals of map reading. We explored physical and digital maps, highlighting their unique strengths and the importance of their complementary use. We delved into essential map elements, including the cardinal directions, symbols, scales, contour lines, and declination, empowering you to decipher maps effectively.

While maps are crucial, their power is amplified when combined with other navigational tools. While maps are crucial, their power is amplified when combined with other navigational tools. The subsequent chapters will delve into compasses, altimeters, and GPS devices, equipping you with a comprehensive understanding of wilderness navigation techniques. We'll start with navigating solely by map in high-visibility conditions in Chapter 2 before introducing these additional tools.

Chapter 2

Navigation Without Instruments

> "I admit that on my last two thru-hikes, I only had maps on my phone.
> Yes, it was risky because phones fail, get crunched, get lost, and die.
> I made it, but what bothered me the most was feeling like I was
> just following a line and unaware of the larger picture or my options."
> — Alison Young, Blissful Hiker podcast, episode 56

INTRODUCTION

The backbone of this book is learning to navigate with five tools: physical maps, digital maps on GPS devices, compass, altimeter, and for when things fall apart, satellite communications for seeking assistance in emergencies. This section emphasizes map-reading skills and the preeminent utility of maps but does not encourage exploring the wild with only a single tool. I strongly encourage you to carry all five navigational tools we explore in this book on every backcountry adventure.

But it is worth pausing on our learning journey for an entire chapter to look closer at the "earth in the palm of your hand." Learning how to find lines of position (LOPs) on your map and the earth is a critical overarching principle that will answer the question "Where are we?" with varying levels of precision. You will learn to use two special LOPs: handrails, serving as guides leading us toward our intended destination, and backstops, acting as alerts that we are near a decision-making juncture or destination. "Trail dead reckoning," a straightforward and practical technique that applies basic math to guide us on trails.

The chapter concludes with fascinating but less critical information about navigating the natural world. Understanding the movements of the sun, moon, and stars contributes to a heightened situational awareness, cultivating a navigator's sixth sense about when it is time to question our navigational assumptions and consult map and instruments.

LINES OF POSITION

If we boil the ocean of navigation information down to its essence, we have *lines of position (LOPs),* linear or at least straightish features that we can both identify on a

KEY TOPICS
LINES OF POSITION
LOCATION
TRAIL DEAD RECKONING
NATURAL NAVIGATION BASICS

map *and* observe or measure in the landscape. Lines of position include those we can see, such as trails, shorelines, and ridges, as well as those we measure, such as compass bearings and elevations. Our excursions occur on the undulating surface of the earth that we represent on a two-dimensional map. Therefore, we know where we are on the map whenever we identify two LOPs that intersect our position. The line of position is the concept that melds the traditional map and compass with GPS, digital maps, and the altimeter to create modern wilderness navigation.

PHYSICAL AND INSTRUMENT LOPS

A wide variety of visible physical LOPs and invisible instrument-derived LOPs are available for navigation. Don't be overwhelmed by the volume—you do not need to find them all. Instead, take solace in knowing you have many choices, but you only need one LOP to guide you on your way or two that intersect under your feet to determine your position.

Physical LOPs. Physical lines of position are those you can see in the landscape and correctly identify on your digital or paper map, and they come in two types:

- **Elongated features.** An easily identifiable elongated feature you can identify on your map and in the landscape is a line of position. Examples include roads, trails, rivers and streams, tree lines, railroad tracks, shorelines, power lines, ridges, gullies, and valleys.
- **Transits.** When two visible landscape features align with your location, this creates an accurate line of position known as a "transit." This is similar to the alignment of a rifle's front and back sights. A transit is useful when the features can be accurately identified on a map because your location lies somewhere along this LOP. A transit can occur by the alignment of such landscape features as peaks, small islands, small lakes, or parts of more prominent features, such as the edge of an island or a distinct feature of a mountain, such as a cliff or col.

> **Example.** Imagine lounging by one of Mount Rainier National Park's beautiful lakes in Figure 2-1, but you are unsure which lake. You then notice Peak 4644 and Peak 5200 form a transit with your lakeside location. The transit, a type of LOP, intersects with only one lake, pinpointing location, as shown by the dotted line in Figure 2-1. This was done with keen observation and a map; no instruments were required.

Instrument LOPs. There are three instrument lines of position; they cannot be seen and require a compass, an altimeter, or a GPS to measure. Instrument LOPs are the primary focus of the rest of this book.

- **A compass is used to measure a bearing. We will explore compass bearings and their use as LOPs in Chapter 3.**

Fig. 2-1, Finding your location at the intersection of two LOPs or a transit.

- **An altimeter is used to measure an elevation.** We will explore altimeters and the use of topographic lines as LOPs in Chapter 4: Third Tool: Altimeter.
- **A GPS is used to measure coordinates.** Coordinates are commonly expressed using the latitude and longitude or UTM systems. We will explore using GPS in Chapter 5: GPS Magic.

Note: bearings are the traditional line of position for sailors to determine (or "fix") their position. Bearings are covered in depth in Chapter 3, but for our purposes here, understand that a bearing is a direction from one location to another, measured in degrees from true north.

PHYSICAL LINES OF POSITION EXAMPLE

Physical LOPs are often easy to find in the landscape. Examine each physical LOP and its label in Figure 2-2 below. Notice how the linear feature is cross-hatched, but its usefulness extends across the landscape, as shown by the arrow. Imagine the landforms from the contour lines to understand each of these LOPs. Then, see how many additional LOPs you can find.

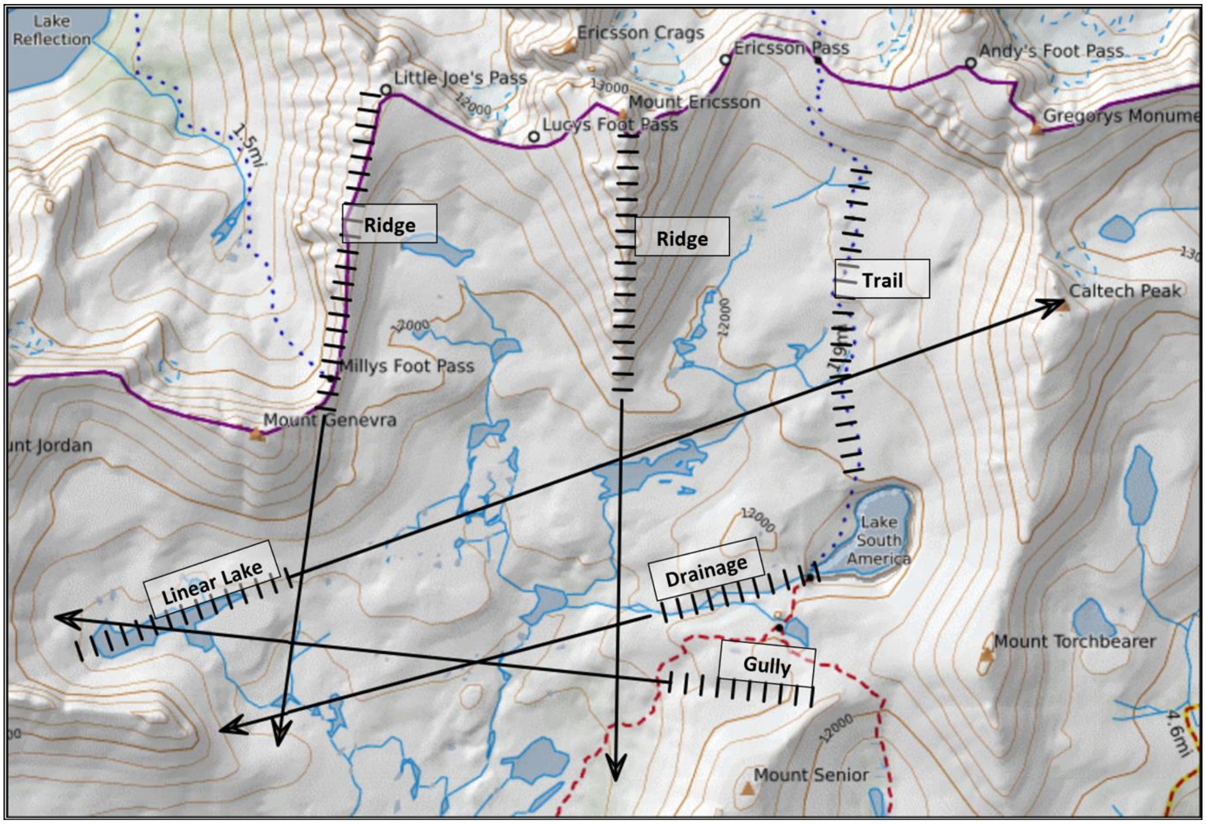


Fig. 2-2, Examples of physical lines of position. Scan the QR code below or use the CalTopo.com/p/8a0NL link to download this map. {artist note. Please simplify this diagram. Less ink.}

USING LINES OF POSITION

Lines of position are, of course, used to answer the question, "Where are we?" But the answer to this question can have three levels of precision:

- **Standing on two LOPs: "We're here."** When two LOPs run under our feet, our location is at their intersection. This is also known as a "point position."
- **Standing on one LOP: "We're somewhere on this line."** When we have only one LOP that runs under our feet, we don't exactly know our location, but knowing we are somewhere on a line is a vast improvement over being "somewhere on the map." When a single LOP can guide us toward our target, we refer to it as a handrail. A single LOP is our normal state when in the backcountry.

- **In a zone[5] of one or more backstops: "We're somewhere in this zone."** A backstop is a LOP that runs somewhat crosswise to our direction of travel, alerting us that we are approaching or have traveled past the next turn or destination. One or more backstops can sometimes define a "zone," meaning an area bounded by LOPs (see "In the zone" below). A backstop answers the question, "Have we gone far enough?"

WHAT IS OUR LOCATION?

As noted above, our normal state is to know we are traveling a handrail, meaning a physical or instrument LOP through the landscape, but not our exact location. Determining our location is an essential topic of the rest of this book, and as we add additional tools and techniques, we can find our location in different ways. Here are a few examples to pique your interest.

Two LOPs example. Imagine you are uncertain of your location on the map in *Figure 2-1*, so you measure a compass bearing to Peak 4644, a peak you can both see and identify on your map. The bearing is measured as due west (270°). We will discuss how to determine bearings using GPS, map, and compass in Chapter 3. Now draw this line of position from the peak to the right (east) across your map toward your unknown position (solid line in *Figure 2-2*). You still don't know where you are, but rather than being *anyplace on the map, you know you are someplace on that LOP.* Knowing you are on a LOP is a vast improvement to your knowledge about your location. If you establish a second LOP that also runs under your feet, you know you are at the intersection of those two lines. Your second LOP does not need to be a bearing to a peak, nor does your first, but continuing with our example, assume we are hiking the famous Wonderland Trail around Mt. Rainier. Your second LOP can be the straightish trail you are hiking. You are at the point on the map where the line to Peak 4644 intersects the line of your trail. Now you are navigating!

Illustration: A Cross-Country Route

Another aspiration for Pacific Northwest scramblers is the rough and rugged Bailey Range Traverse in Washington State's Olympic Mountains. The northern approach to this cross-country route leaves the trail near Appleton Pass and ridge walks to High Divide-Sol Duc Park on the dotted line Figure 2-3 below. Imagine that while doing this traverse, you ascend what you believe is Haigs Lake Peak, but you want confirmation. From its summit, you notice two visible transits. The first is the alignment of Seven Lakes Overlook and Haigs Lake with your position. The second is the alignment of Peak 5900 and the knoll above Spread Eagle Pass with your position. Each transit confirms your position because each transit only aligns with one peak in your vicinity, Haigs Lake Peak. Together, they add confidence. Later, we will learn to use other lines of position, such as:

[5] "Zone," as used in navigation, has two meanings. Here, a zone means an area bounded by LOPs. Do not confuse this with zone, as introduced in Chapter 5, meaning a component of the UTM system.

Compass. Measure compass bearings on the ridges leading from Haigs Lake Peak or other visible peaks and features.

Altimeter. Use an altimeter to confirm your location's elevation with the map's elevation for Haigs Lake Peak.

GPS and digital maps. Confirm your location using digital maps or GPS coordinates on your phone.

Yes, modern navigational tools allow for several alternative methods to determine location. While this initially sounds complicated, remember that in this high-visibility situation, any one of these methods would be enough to confirm our location, allowing for flexibility, preference, and redundancy.

Fig. 2-3. Transits that are visible from Haigs Lake Peak. *[Add label or waypoint to Haigs Lake]*

Illustration: A Cross-Country Route On Your Own

While continuing the cross-country route from Appleton Pass to High Divide-Soleduck Park, you ascend what you believe is Peak 5700, southwest of Haigs Lake Peak (there are two Peak 5700s on the map), but you want confirmation. Open Map 1 in *Figure 2-4* and find at least five physical LOPs visible from the summit. The highlights on Map 1 show exactly what parts of the landscape are visible from the summit. This is known as a "viewshed" and is challenging to discern from a map without the help of a computer to do the math. Only use the shaded landscape areas to find lines of position. Map 2 shows a variety of LOPs that are in line with Peak 5700. For extra credit, speculate what instrument LOPs might be available and helpful if visibility were reduced to 100 feet (30 meters).

Map 1: **Find the LOPs**	**Map 2:** **With Suggested LOPs**
CalTopo.com/p/0C7K1	 https://bit.ly/3NRPTMx

Fig. 2-4. Finding lines of position.

SPECIAL LINES OF POSITION: HANDRAILS AND BACKSTOPS

Lines of position are the threads that hold navigation together, and two special types of threads are handrails and backstops.

HANDRAILS

Navigating involves following a LOP or moving within a zone bounded by LOPs. A physical LOP could be a road, trail, shoreline, stream, ridge, power line, or any linear landscape feature. If it is an instrument LOP, it is a bearing, an elevation, or a GPS coordinate. A physical or instrument LOP can guide your footsteps toward your destination, like a handrail on a staircase. A physical LOP handrail requires less focused attention than using a compass, an altimeter, or GPS, making it advantageous whenever available. Nevertheless, relying too heavily on any handrail can inadvertently diminish our situational awareness with insufficient attention to the changing terrain. This loss of situational awareness happens on the freeway when our mind wanders, causing us to miss an exit or on the trail when we overlook a subtle intersection. The antidote is to keep your situational awareness high by continually asking three questions, known as The Situational Awareness Loop[6]:

- **Where are we?** Continually challenge your assumption, your hypothesis, about your location by asking, "Where are we?" One way to do this is to frequently orient the map and see if the landscape you observe confirms or rejects your hypothesis about your

6 These three pillars are discussed in more depth in Chapter 3: The Situational Awareness Loop.

location. To orient the map, keep your body aligned with your direction of travel, align the map with north (we will soon learn how to do this with a compass), and verify if the landscape around you corresponds with the paper map. Does the LOP (trail, ridge, etc.) under your feet align with the map? If it does not, you will be tempted to turn the map away from a north orientation to force it to align with the trail or other LOP you are following. Resist this temptation to turn the map; you might not be where you think you are! Answering the question "Where are we?" is a primary objective of navigation.

- **Where are we going?** Continually think about the goals. The group should discuss "Where are we going?" "What is our agreed route?" and "Do the goals need any revision based on conditions including time, weather, or condition of the party?"
- **What do we expect?** Keep the entire party engaged in discussing the expectations about achieving the objective. What do we expect to see en route? When and where will we be switching to a new handrail?

It is better not to follow some handrails too closely. Stream beds and shorelines are often quite brushy and challenging. Gullies are the garbage collectors of the wilderness, accumulating trees, boulders, and debris in their low points, making travel inconvenient. Cliffs can make distinct handrails, but their edges must be treated with caution. Meandering creeks take the long way down. Each of these handrails might make good guides but are best paralleled at a distance that allows you to keep them in sight but avoid their challenges.

On the other hand, ridge tops typically allow easy walking with less vegetation, and debris falls away toward lower elevations. The views can be enjoyable and practical by allowing you to see more of your surroundings and raising your situational awareness. A good strategy to reach a ridge top can be to climb a more gradual spur.

Handrail Illustration: The Route to Camp Muir

Many northwest hikers aspire to walk the 500-foot-wide corridor of unglaciated snow and rock to Camp Muir at the 10,000-foot elevation level on 14,411-foot Mt. Rainier. The route is listed as one of the "ten most dangerous hikes in the US[7]," not due to the hike itself but because it's wedged between the Nisqually, Cowlitz, and Paradise glaciers. A navigation error could lead to having a mountain feature named after you[8]. Fortunately, a convenient rocky ridge to the east of the route is shown by the hatched line in Figure 2-5. This handrail is formed by the line of position formed by the ridge that connects Panorama Point, McClure Rock, The Sugarloaf, Moon Rocks, Anvil Rock, and Muir Peak just east of Camp Muir. On a bluebird day, your navigation will be on point if you keep your handrail about 400 to 800 feet (125 to 250 m) to the east. But Rainier makes its own weather, and the quick onset of a whiteout would make you wish you had

[7] The 10 Most Dangerous Hikes in America: Muir Snowfield, Mt. Rainier, WA, Backpacker Magazine, published October 27, 2008.

8 In 1897, Professor McClure (no relation!) from the University of Oregon was returning from a scientific expedition to Camp Muir. As they descended, he jumped onto the as-yet-unnamed McClure Rock and shouted as he plummeted onto the Paradise Glacier, "Don't go this way! It's slippery!"

also read Part II of this book, Low-Visibility Navigation by Instrument.

FAR ENOUGH?

Whenever we follow a trail, river, ridge, gully, or any line of position, there is the question, “When have we followed the linear feature far enough?” There are four primary ways to answer this question:

1. **Determine location by Finding or measuring a second LOP.** Finding and measuring two LOPs that run underfoot will tell you your location.
2. **Directly measure the distance traveled.** Counting steps or “pace counting” is a favorite technique for the military, who often travel rugged terrain at night. A good soldier knows their pace count, or steps per kilometer, traveling uphill, downhill, level, or even crawling. See Section 3: Special Users, Military Methods.
3. **Use the elapsed time to estimate the distance traveled.** See “Trail Dead Reckoning” below for this practical on-trail navigation method.
4. **Use a backstop.** Using a backstop as a catching feature is a practical method to answer the question above.

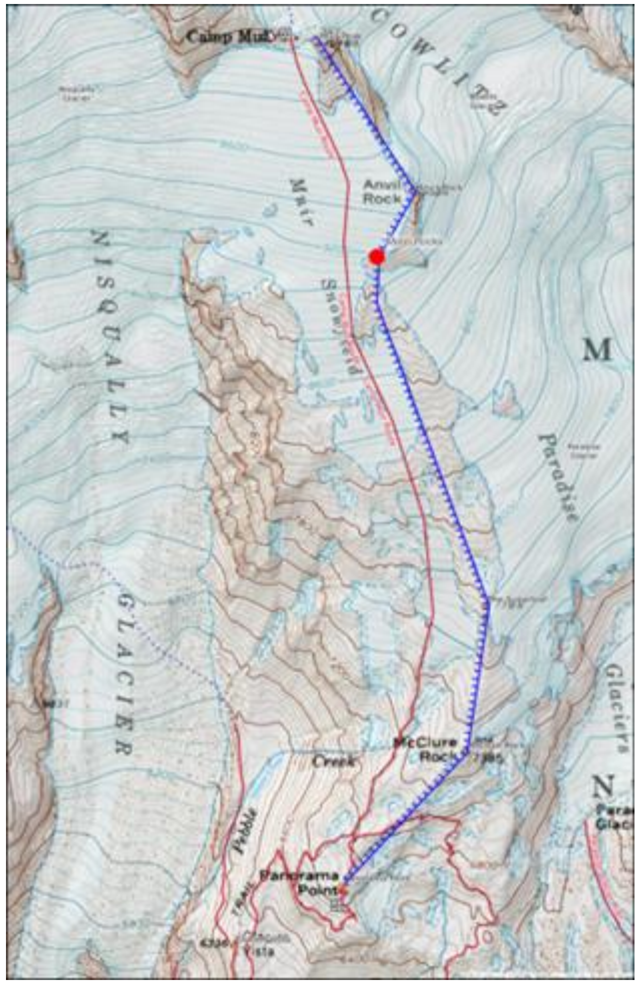


Fig. 2-5. Route from Panorama Point to Camp Muir with handrail to the east, indicated by the hatched line.

BACKSTOPS

Backstops are the second special line of position. While handrails guide our steps, backstops tell us when we have gone far enough or even too far. Sometimes, one or more backstops can define a “zone” (see “In the zone” below).

"That's far enough!": Backstops as a catching feature. We should consider what to expect as we travel along or aside our LOP. When walking a trail, numerous landscape features can alert us that we have gone far enough or even too far. Streams, ridges, roads, and powerlines can be obvious backstops. Changes to the trail itself, such as direction, steepness, or quality, or changes to the terrain, such as slope, vegetation, or direction, are more subtle but can all alert us to when a change or stop is required. If we are walking a ridge that ends in a cliff, following a route description that says we should descend the vague "obvious gully," the cliff is a clear backstop that alerts us that we have overshot the intended gully.

BACKSTOPS

After four days of off-trail hiking in the High Sierra, we were descending a swampy hillside as we approached the desired trail that ran perpendicular to our direction of travel. The trail was our way home and our backstop. The map marked the trail with an unmissable red line. As a second backstop, we also noted the trail's elevation to estimate how much longer we had to dodge mosquitoes. When "we should be there soon" turned into a longer-than-expected walk and the beginning of a descent into an unexpected gully, we consulted the altimeter. We had missed the not-so-obvious trail.

After backtracking and searching, our bright red line was a little-traveled boot path, barely more conspicuous than an animal trail.

In the zone: Backstops to define zones. If we use multiple backstops, we can sometimes define areas or zones where you are on the map and "exclusion zones" or places on the map where you cannot be. For example, let's say we left Lake South America in Figure 2-2 and were generally headed north to explore the lakes in this High Sierra cirque, and we have not climbed any steep ridges. Our situational awareness tells us that we are in a zone limited to this cirque, bounded on the west, north, and east by steep ridges that we know we have not crossed. We also know that we are north of Lake South America as we have been aware of the sunshine on our shoulders as we traveled north. Without further navigation, we know the zone where we must be and the LOPs that form its boundaries. By definition, we can exclude everywhere else in determining our location.

Note that this method is effective only if you know your starting point and can anticipate the LOPs that define the zone you are about to enter. By anticipating these zones in advance, you can ensure that you have yet to cross any of the LOPs that mark the boundary of the zone. In our previous example, three LOPs were cliffs that would be difficult to pass without notice. However, the southern boundary of this zone is less distinct, requiring you to stay north of Lake South America. If you were unaware that this lake was the southern boundary, you could unintentionally cross it, rendering this concept ineffective. Common LOPs that indicate zone boundaries include roads, rivers, and cliffs. Trails can also be used, but please refer to the cautionary information in the inset labeled "*Backstops.*"

TRAIL DEAD RECKONING

Trail dead reckoning[9], or TDR, is the simplest of the navigation techniques in this book and one of the most practical and frequently used, especially on well-maintained trails where your speed (rate of travel) can be reasonably estimated. Results will be less consistent when off-trail or on steep or rugged trails. While we strongly suggest wilderness navigators always carry the five navigation tools, TDR only requires a map and a watch. TDR requires a math formula, which is:

Rate x Time = Distance, where:

- **Rate (r)** is our estimated speed while moving over the terrain to be traveled. This speed is measured in miles per hour (mph) or kilometers per hour (km/h);
- **Time (t)** is measured in hours; and
- **Distance (d)** is measured in miles or kilometers.

For example, if we hike the Sunny Lake Trail at a rate of 2 mph and our hiking time (excluding stops) is 4 hours, the distance traveled must be about 8 miles since 2 times 4 equals 8. The formula ignores stops, so after using the formula, add an allowance for stops. A metric example is if we hike a trail at a rate of 3 km/h and our hiking time (excluding stops) is 4 hours, the distance must be about 12 km since 3 times 4 equals 12.

The magic of math means that we only need to know two of the three inputs to the formula. In example 1, we know our rate and the elapsed time, so we can calculate the distance traveled. In example 2, we know the distance and rate, so we can calculate the time, or the number of hours, the hike will take:

- **Example 1: Predicting hiking time, our ETA at Cloudy Lake.** The hike to Cloudy Lake is 12 miles (19 km) with modest elevation gain on a good trail with a consistent grade. Hiking with overnight packs, the group estimates they can travel 1.5 mph. If we rearrange the formula to solve for time, we get distance / rate = time, or 12 mi / 1.5 mph = 8 hours (metric version: 19 km / 2.4 km/h = 8 hours). If we add one hour for breaks, the walk should take about nine hours. If they leave the car at 8am and allow one hour for breaks, the group should be at the lake at about 5pm. The group can monitor its progress with a watch.

  Monitoring the time is a key to situational awareness, and be aware that estimates of hike rates are often optimistic. Frequently return to the situational awareness loop in Chapter 3.

9 Dead reckoning is the traditional navigation technique used by sailors during inclement weather when celestial navigation fails. From a known location, sailors would measure the bearing to their target location on their charts (maps) and sail "dead ahead" or by "dead reckoning," using only the compass and calculations to offset currents. The sailors could reassess their location when the celestial lights came back on. Chapter 3 will discuss the terrestrial version of dead reckoning as a last-choice backup technique for poor visibility when other navigation forms won't work. Here we are discussing the simple and practical technique we call "trail dead reckoning."

- **Example 2: Estimating distance traveled toward Windy Pass.** The hike to Windy Pass is 10 miles (16 km) with modest elevation gain on a rough trail with a consistent grade. Hiking with day packs (including the Mountaineers Ten Essentials), the group has been traveling since 8am for 3 hours and estimates they have been traveling 2.5 mph. They would like to know how much farther it is to Windy Pass to decide if they should continue. We calculate for distance as rate x time = distance, or 2.5 mph x 3 hours = 7.5 miles (metric version: 4 km x 3 hours = 12 km). The group has traveled about 7.5 miles (12 km) and has about 2.5 miles (4 km) to go. They decided to stop for tea and Christmas cake.

AVERAGE HIKING RATES

The TDR formula above can also compute our personal hiking rate. If we rearrange the formula, we get rate = distance / time. If we find we walked 12 miles in 8 hours, 12 mi / 8 hours = 1.5 mph (metric version: 19 km / 8 hours = 2.4 km/h). Remember that our average rate is affected by our fitness, age, pack weight, trail quality, elevation change, elevation, weather, and time spent not hiking. Considering these caveats, the examples in Table 2-1 Figure 2-8 should be a good starting point while you develop your personal hiking rate. It shows the typical hiking rates and time required for a hike of 10 miles, total mileage. Vertical feet per hour for off-trail travel is better than mph or km/h.

TABLE 2-1. COMMON HIKING RATES ON- AND OFF-TRAIL

TRAIL OR ROUTE (Elevation gain)	HIKING RATE	EXAMPLE
Gentle trail (< 200 feet per mile or 50 m/km)	2 to 3 mph (3 to 5 km/h)	A 10-mile (16 km) hike should take about 3 to 5 hours + stops
Moderate trail (about 500 feet per mile or 100 m/km)	1.2 to 2 mph (2 to 3 km/h)	A 10-mile (16 km) hike should take about 5 to 8 hours + stops
Steep trail (1,000+ feet per mile or 200+ m/km)	0.8 to 1.4 mph (1.3 to 2.3 km/h)	A 10-mile (16 km) hike should take about 7 to 13 hours + stops
Off-trail travel (about 500 feet per mile or 100 m/km)	Allow 500 to 1,000 feet (150 to 300 m) of elevation gain per hour	An off-trail hike that gains 3,000 feet (900 m) should take about 3 to 6 hours + stops

Common hiking rates on- and off-trail. Examples of a 10-mile hike are for total mileage, meaning a one-way trip of 10 miles, or a round trip on a 5-mile trail. Vertical feet per hour for off-trail travel is better than mph or km/h.

NATURAL NAVIGATION BASICS

If you are in a hurry, the section below can wait until you want to read some fascinating but less critical information about navigating through the natural world.

In high school, I had an afternoon job at the Cobb Building in Seattle, developing medical X-rays. After developing, I would put the film on a wall-mounted light box ready for the doctor to diagnose disease or fracture. My 15-year-old eyes saw nothing unless there was a metal pin or screws. The radiologists would then dictate a 10-page report from the subtle signs they could see in the black-and-white image.

Similarly, experienced navigators keep their situational awareness high by keenly observing the terrain and sky, details the beginner does not notice. Here are observations you can make to sharpen your vision. While you are unlikely to rely on such observations for navigation, they will help you connect with the natural world as you walk its wild spaces.

Sunrise, sunset (in the Northern Hemisphere). While we know that sunrise is east and sunset is the west, this is precisely true only on the first days of spring and autumn, the equinoxes, when daylight and dark are equal at 12 hours. As we move from the spring equinox (in late March) three months toward the first day of summer (in late June, the summer solstice and longest day of the year), the sun rises and sets farther north each day. For six months after the summer solstice, sunrise and sunset occur farther south each day. After the first three months, the sun is at the autumnal equinox, and after three more months, the sun has reached the southern extent of its journey on the winter solstice in late December, the shortest day of the year. One season following another, day by day, the sun then begins its journey north.

Sunrise, sunset (in the Southern Hemisphere). While we know that sunrise is east and sunset is the west, this is precisely true only on the first day of spring and autumn, the equinoxes, the two days when daylight and dark are equal at 12 hours. As we move from the spring equinox (in late September) three months toward the first day of summer (in late December, the summer solstice and longest day of the year), the sun rises and sets farther south each day. For six months after the summer solstice, sunrise and sunset occur farther north each day. After the first three months, the sun is at the autumnal equinox, and after three more months, the sun has reached the northern extent of its journey on the winter solstice in late June, the shortest day of the year. The sun then begins its journey south.

See Figure 2-6.

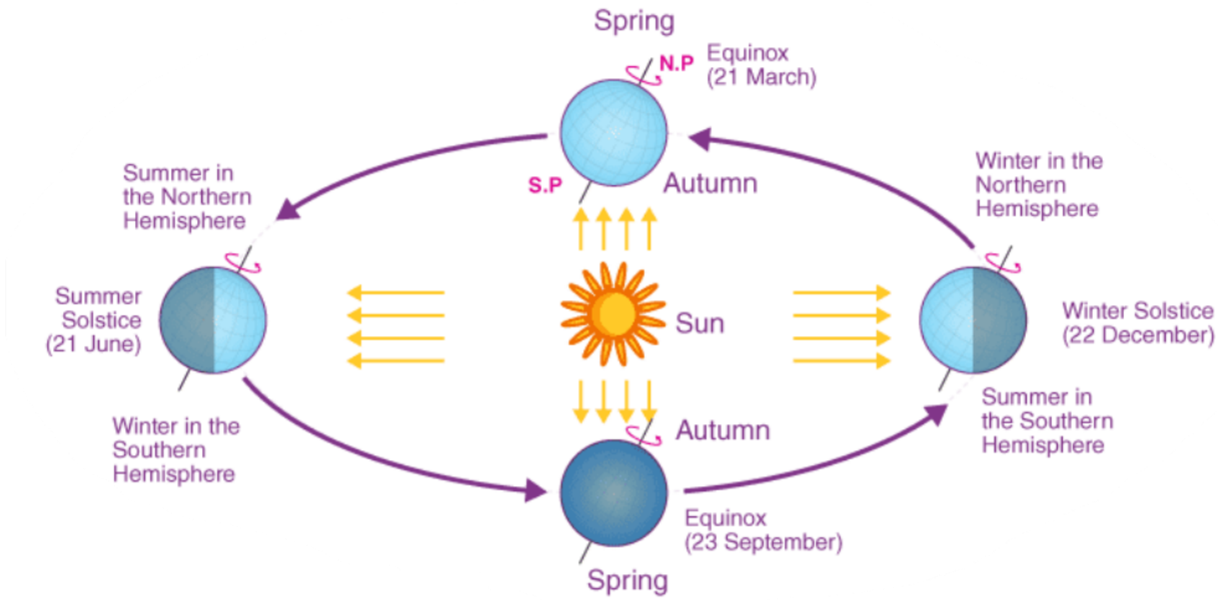


Fig. 2-6. Equinoxes and Solstices.

This significant variance in the direction of sunrise and sunset from due east and west is called amplitude. At the equator, the maximum amplitude is 23.5°, the earth's tilt. At 20° latitude north or south, the maximum amplitude is 25°; at 40° latitude (N or S), the maximum amplitude is 31°; at 60° latitude (N or S), the maximum amplitude is 53°. Taken to the extremes, past the Arctic Circle and the Antarctic Circle, the maximum amplitude is so great that sunrise and sunset overlap, giving us days when the sun never sets or never rises, depending on the season. The absolute extremes are the poles, where the sun rises at the equinox and stays up for six months until the next equinox when the sun sets, followed by weeks of twilight and then about six months of night. When it is daylight at one pole, it is night at the other.

So, depending on the time of year and your latitude, you can estimate where the sun will rise and set based on knowing east and west with a compass. Similarly, you can estimate east and west without a compass, depending on the time of year, your latitude, and where the sun rises and sets. Figure 2-7 can help you visualize the relationship between sunrise and sunset with the cardinal directions east and west.

TILT OF THE EARTH: 23.5°. Earth and the seven other planets orbit our sun in the same orbital plane. The earth's axis of rotation is tilted 23.5° away from perpendicular to this orbital plane, with some interesting effects, see Figure 2-6a:

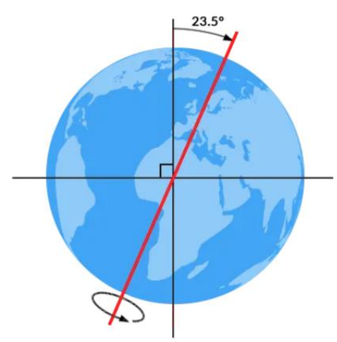


Fig. 2-6a. 23.5° tilt of the earth.

- Half the year, the northern hemisphere points more directly toward the sun, and half the year, the southern hemisphere points more directly toward the sun. This is the cause of our seasons.
- The farthest latitude from the poles, where there is at least one day where the sun never sets and one day where the sun never rises, is 23.5° from the poles. We call these latitudes the Arctic Circle and Antarctic Circle. Their latitudes are 66.5° N and S, respectively, or 90° minus 23.5°.
- The farthest latitude from the equator, where the sun is directly overhead for one day each year, is 23.5° N, and S. The 23.5° N latitude is called the Tropic of Cancer. Its southern twin at 23.5° S is called the Tropic of Capricorn.

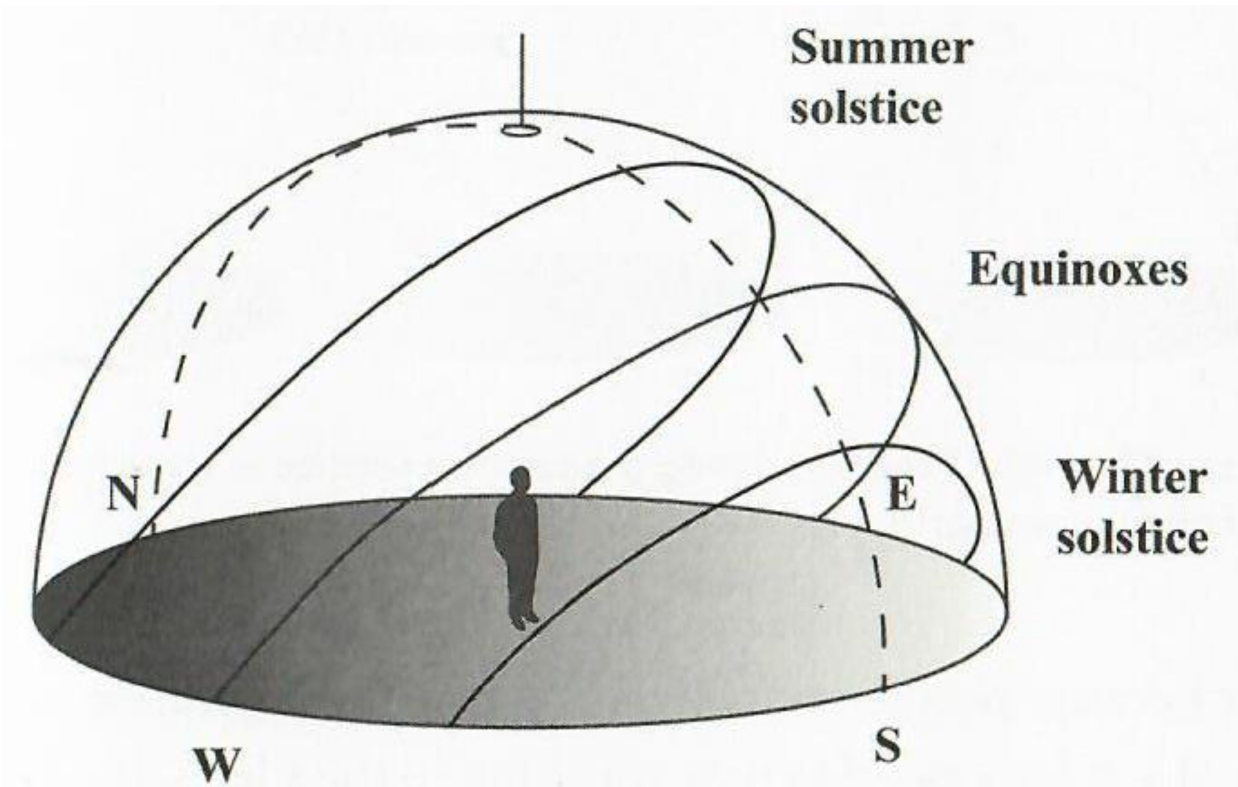


Fig. 2-7. The ecliptic, shown at a latitude of 42° north, has an angular width here of about 60°.

The ecliptic. The three solid lines arcing over the head of the observer in Figure 2-7 trace the sun's path on different days during the year. These paths form a band called the ecliptic, with its lower edge marking the sun's winter solstice path and its upper edge marking the summer solstice path. Experienced navigators instinctively anticipate the sun's movement through the sky and the shadows on the ground, but it's a crucial skill often overlooked for beginners. (See "Shadow Awareness" below.)

Knowing your latitude (Chapter 5) helps predict the sun's daily arc and vice versa. While we don't typically carry specialized instruments, a good approximation can be made with an inclinometer, using its shadow for alignment, NOT by looking directly at the sun.

Here's the sun's angular height above the horizon at solar noon (its highest point):

- **Equinoxes.** 90° minus your latitude.
- **Summer solstice.** 90° minus your latitude plus 23.5°.
- **Winter solstice.** 90° minus your latitude minus 23.5°.

How long until dark? A frequent practical problem is knowing how much time remains until dark. This knowledge can help you avoid getting lost and ensure you have enough time to reach your destination before nightfall. The best way to know the minutes of daylight remaining is to know the current time and the time of sunset. In addition, twilight provides additional cushion. See the next section below.

The estimation method will give you a practical feel for the time until sunset. The sun travels its 24-hour arc through the sky, taking 1,440 minutes to cover 360°, or 4 minutes for each degree (1440 / 360). A reasonable estimate for measuring degrees of arc is to use the fact that the width of a human finger at arm's length is about 2° wide, and so the sun takes 8 minutes to cover the width of one finger or travel 2°.

When the sun is low on the horizon and safe to observe, you can gauge the remaining daylight by using your fingers to estimate the minutes until sunset. To make this estimate, extend your hand or hands at arm's length and count the number of fingers needed to cover the distance from the sun to the anticipated spot on the horizon where it will set. For example, measuring four fingers from the sun to the horizon would suggest approximately 32 minutes until sunset (4 x 8 minutes). Refer to Figure 2-8 for visual guidance.

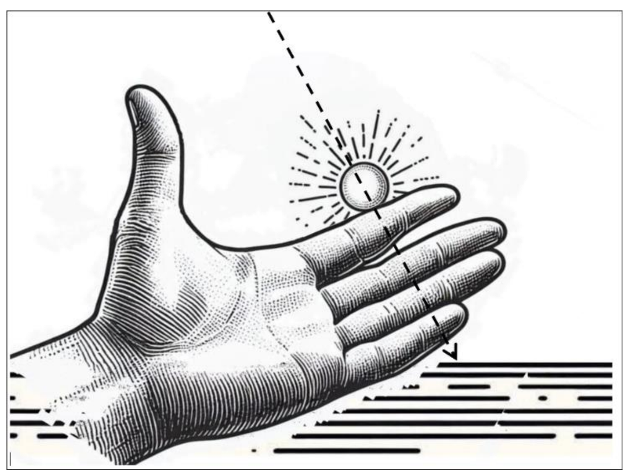


Fig. 2-8. Estimating time until sunset. Note that the angular diameter of the sun as shown is significantly exaggerated. Its only about 0.5°, or one-quarter the width of a finger. The moon is approximately the same.

Note that at the equator, the sun moves vertically toward the horizon. As you move north or south from the equator, the sun sets at a gradually flattening angle. For example, in the northern US, this angle will be about 45°. Each finger indicates 8 minutes of remaining day. If you use all ten fingers, at 8 minutes per finger, you have about an hour and twenty minutes until sunset. Don't get too precise about your measurement since the method is intended as a quick estimate.

In many places, hills will prevent you

from seeing the horizon. You can use this method to estimate how many minutes remain until the sun moves behind the hills. At that point, the temperature will begin to drop, but you may have a long time until darkness. Alternatively, you can use this method by estimating the location of the actual horizon.

Twilight. "Civil twilight," as it is officially known, is the time after sunset when outdoor activities can continue until we reach for our headlamps. It is significant until the sun drops more than 6° vertically below the horizon. The duration of this 6° drop depends on the latitude and the time of year, which affect the sun's angle as it hits the horizon.

When the sun drops below the horizon, the upper atmosphere continues to scatter sunlight, illuminating the lower atmosphere and Earth's surface. Where there is no atmosphere, such as on the Moon, there is no twilight. When the sun drops behind near hills, the sun has not actually set, so the atmosphere will continue to illuminate the area until the sun sets behind the actual horizon, plus regular twilight.

- Near the equator and for about 30° of latitude north or south, the sun travels in a high arc and sets nearly vertically. With the sun's apparent movement of one degree every four minutes (see discussion above), twilight lasts about 24 minutes. Locations at about 30° north include San Diego, Jacksonville, Cairo, New Delhi, and Shanghai. Locations at about 30° south include Buenos Aires, Cape Town, Perth, and the northern tip of New Zealand.
- At 45° of latitude north or south, twilight lasts about a half hour. Locations at about 45° north: Seattle, Toronto, Maine, Milan, Beijing, Sapporo. Locations at about 45° south: southern tip of New Zealand, Patagonia.
- At 60° north or south, twilight lasts about an hour, more near the solstices and less near the equinoxes. Locations at about 60° north: Anchorage, Whitehorse, Reykjavik, Stockholm, Moscow; and south: Drake Passage. Near and beyond the Arctic and Antarctic Circles at 66° north or south, twilight can last all night. These all-night sunsets are called "white nights."

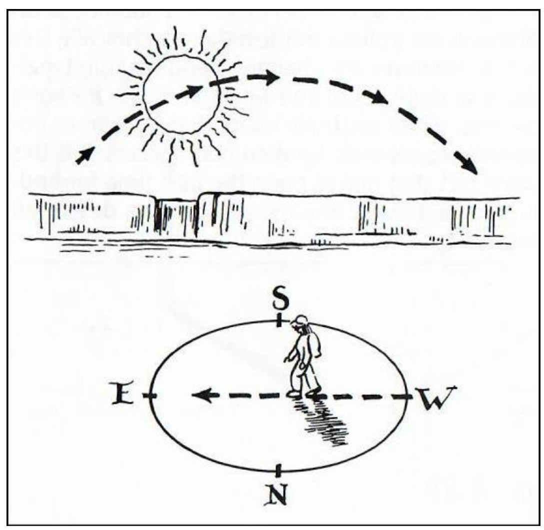


Fig. 2-9. Shadows in the northern hemisphere move from roughly west at sunrise, clockwise toward north at midday, and roughly east at sunset.

Shadow awareness. Except when weather intervenes, experienced outdoors folks are continuously aware of the daily arc the sun takes through the sky along the ecliptic. They know roughly where old Sol should be shining at any hour. In the northern hemisphere, the sun will be directly south at solar noon, when the sun reaches its apparent highest point in the sky, halfway between sunrise and sunset (not noon). They notice the direction of shadows as the day progresses and know they are 180° from the sun's position. Starting with sunrise, shadows point roughly west and then move like a clock (or sundial!) toward the north at midday and roughly east at sunset. See Figure 2-9.

> **TWILIGHT**
>
> Twilight is the time after the sun sets and before we reach for our headlamps. For latitudes between 45° north and south, twilight lasts about a half hour. At 60° north or south, twilight lasts about an hour. North of 65° north or south, twilight can last all night.

In the southern hemisphere, shadows point roughly west at sunrise and then move *counterclockwise* (like a sundial) toward the south at midday and roughly east at sunset. See Figure 2-9.

All bets are off near the equator (technically between the Tropic of Cancer and the Tropic of Capricorn) and near the poles (north of the Arctic Circle or south of the Antarctic Circle). Near the equator, the sun's ecliptic can arc north or south of you depending on the time of year—and occasionally is directly overhead. Near the poles, there can be no sun or shadows during winter. The sun's low angle and long days can result in complex circular or spiral patterns.

Superstars. The Earth, the celestial stage for navigation, seems to stand still inside a vast celestial globe that rotates around us. This imaginary celestial globe's axis aligns with Earth's axis, and the stars, positioned far beyond our solar system, appear fixed on the inner surface of this celestial sphere. This sphere seemingly spins from east to west as it revolves around us. In our analogy, the two points forming its axis of rotation seem motionless. At its northern axis lies the bright star Polaris, also known as the North Star. Unfortunately, there is no equivalent "South Star" at its southern axis.

Although it might seem that the Earth's rotation around the sun would interfere with the stars remaining apparently stationary to one another, the vastness of space makes our orbit a tiny rounding error. The naked-eye-visible stars, typically 100 to 1000 light years away, form the stationary backdrop of our celestial theater. In contrast, the celestial wanderers are the sun and the seven planets, which don't move in unison with each other or in relation to the cosmic backdrop of stars. The term "planet" comes from a Greek word meaning "wanderer," but at least they wander through the sky along an arc we call the ecliptic.

The arc of the cosmic train of the sun and planets varies with the seasons, as illustrated in Figure 2-9, gradually rising in the sky until the summer solstice and falling until the winter solstice in a slow annual procession. But the moon is a maverick, as discussed in the section "Lunacy" below, and presents unique challenges if we attempt to use it for navigation.

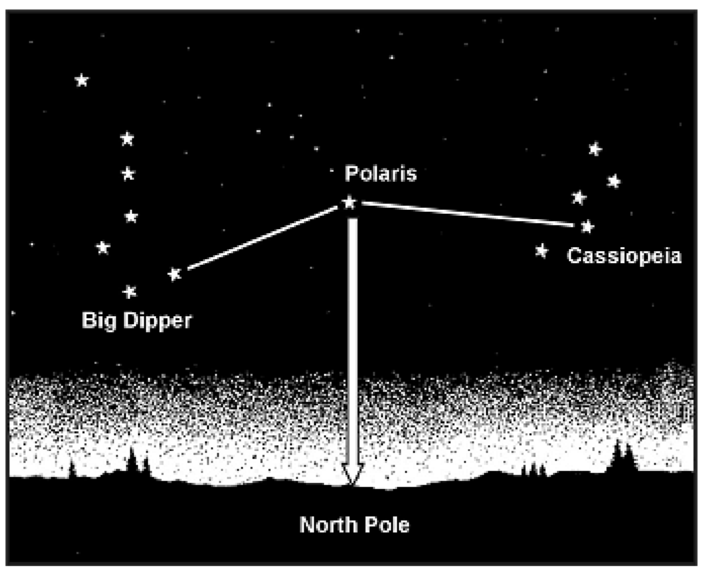
Polaris the North Star. The North Pole marks the northern tip of the Earth's axis of rotation. If we think of the North Pole as an actual pole extending 323 light years to the stars, it would touch Polaris, the North Star.

Polaris, at a fixed height above the horizon, provides a reliable reference point for navigation. Its angular height in degrees does not vary[10] with the seasons and corresponds to one's latitude. In the early 1700s, mariners developed the octant and sextant to measure this angle accurately. This accurate determination of their latitude meant they knew precisely how far north or south they were. While longitude, or how far east or west they were, remained a more complex problem for another century, we can still estimate latitude using our hand to measure the angle, as we estimated the time until sunset above. This measurement should be your latitude. The North Star's angular height increases until it reaches 90°, directly overhead, at the North Pole. Its angular height decreases until it reaches 0°, directly on the horizon, at the equator. The North Star is difficult to see south of 10° N latitude and not visible south of the equator.

Hiking at night with a good headlamp and a pack of essentials is a joy. On a clear night, keeping an eye on the North Star can help keep you oriented, and a short nighttime excursion from camp can avoid becoming an ordeal. While the North Star is conveniently positioned, it is not exceptionally bright. Fortunately, we have helper constellations to point it out.

The Big Dipper (or Plough in the UK and Ireland) is the first helper constellation of the seven brightest stars from a larger constellation called Ursa Major. The Big Dipper resembles a giant soup ladle where the two stars forming the lip of the ladle point close to the North Star. The distance is about five times the distance between the stars that form the lip. If the night is clear enough, you can confirm you found the North Star using the smaller and dimmer constellation called the Little Dipper, which is a part of the constellation Ursa Minor. The North Star forms the end of the handle of the Little Dipper, which pours its soup into the Big Dipper. See Figure 2-10.

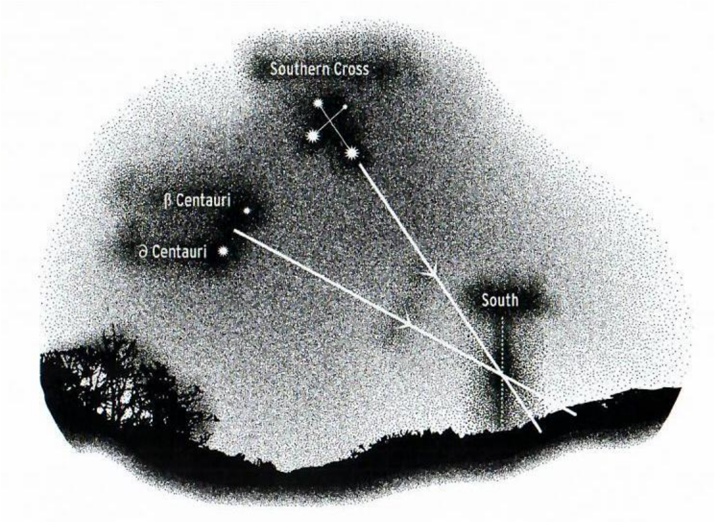
When weather obstructs the Big Dipper or is too low in the sky to find on its counterclockwise rotation around the North Star, the constellation



Fig, 2-10. Using the Big Dipper or Cassiopeia to find Polaris, the North Star.

[Artist note: 1. Label the "Little Dipper." 2. Label Polaris as "North Star or Polaris." 3. Change

10 The North Star's position, in the short run, does not vary. In the long run, as the sun continues its quarter-billion-year orbit of our Milky Way galaxy, the stars become rearranged on our celestial globe. In 12,000 years, Polaris will have drifted off and abandoned its post as the North Star. Vega, the fifth-brightest star in the night sky, will take its place as the North Star.



Fig, 2-11. Finding south in the southern hemisphere using the Southern Cross.

Cassiopeia can often help. Cassiopeia, which resembles a giant W or M about the size of your outstretched palm, is on the opposite side of the North Star from the Big Dipper. If you imagine a line that starts at the bottom of the first of the two valleys of the W and bisects the valley with a length about twice the width of the W, it points close to the North Star. See Figure 2-10.

Southern Cross. As noted above, there is, unfortunately, no bright star at the southern axis of our celestial globe. Still, a workaround exists using the constellation Southern Cross and its trailing two stars, as illustrated in Figure 2-11. While the Southern Cross (or "Crux") is quite dim compared to the Big Dipper or Cassiopeia, its four stars form a distinctive kite shape. The Southern Cross can be confirmed or even located by two bright stars that trail it during its *clockwise* journey around the celestial south pole. The Southern Cross, in addition to being dim, resides in a bustling section of the sky with the Milky Way as its backdrop. For these reasons, using a star-finding app on your phone can be easier when first learning to find the Southern Cross.

Once you identify the Southern Cross, it becomes most useful when it stands vertically in the sky. In this position, its longer axis points close to south. At other times, determining south involves imagining the intersection of two lines: the first is drawn through the cross's long axis, and the second is perpendicular to the two trailing stars. This intersection marks the southern axis, the spot where we would place a "South Star" if we could. South is directly below this imaginary point on the horizon.

Lunacy. Using the moon, the brightest object in the night sky, to keep our bearings at night is challenging. As discussed above, the sun's path through the sky is highest at the summer solstice and lowest at the winter solstice. The angular width of this band we call the ecliptic, is smallest near the equator at 47° and increases in size as you move toward the poles, losing meaning beyond the Arctic and Antarctic circles. The sun's daily arc is higher each day after the winter solstice and lower each day after the summer solstice in a

UNNATURAL NAVIGATION

A critical part of navigation is to observe evidence of others' passing. While we think of the wilderness as pristine, evidence of others' passing is often there for the keen observer. Our fellow hikers leave footprints, rocks worn smooth of moss, cairns, and the occasional bit of stray litter. Trail builders' tools leave deliberate yet subtle scars on the landscape: sawed logs, clipped brush, dynamite blast patterns, and the obvious bridges, blazes, and signs. None of these bits of evidence mark the routes of animals, meandering men, or wandering women. Their presence indicates you are on a purpose-built trail, although perhaps not the trail you want.

predictable annual cycle. The moon also moves within this band plus another 5° at the top and bottom ends, caused by the tilt of its orbit compared to the Earth's. Not only is the band of the ecliptic wider for the moon, but its path within the band also rises and falls on a monthly cycle rather than the annual cycle of the sun. This cycle (27.3 days), called a sidereal month, differs from the moon's lunar cycle, the time between full moons (29.5 days). So, while the moon is always found within a band bounded by the annual extremes of the sun's ecliptic, plus another 5 degrees on both sides, it is difficult to predict where, within this band, you will find the moon or where the moonrise and moonset will be. Using the Moon for navigation is challenging.

Crude Navigation. Despite its somewhat crazy path, the moon can still be a crude tool for keeping your bearings:

- Outside the polar regions, the moon rises in the east and moves toward the west, where it sets. Observing the position of the moonrise and moonset can provide a rough sense of direction, especially when combined with landmarks or terrain features.

- A *full moon* always rises at sunset and proceeds somewhere along the ecliptic. In the northern hemisphere, we find the full moon in the southeast in the evening, about south in the middle of the night, and in the southwest in the hours before dawn. But every night after the full moon, the moon rises about 50 minutes later. Don't make the mistake of thinking that the moon in other phases will be in the same position along the ecliptic as the full moon.

- A half-illuminated moon with the lit side facing west (formally a first quarter moon) is at its highest point about sunset and sets about midnight.

- A half-illuminated moon with the lit side facing east (formally a third quarter moon) rises at about midnight and is at its highest point at about midnight.

- At mid-latitudes, the "crescent line" created by the points of a crescent moon, or the line formed by a quarter (half-illuminated) moon, when extended to the ground, points very roughly south (north in the southern hemisphere). This is more accurate when the moon is higher in the sky.

One cycle of the moon. During a four-month overland trip across Africa, this Seattle city dweller spent a month crossing the Sahara Desert on the back of an old Bedford army truck. At 23 years old, I had never experienced a complete 28-day cycle of the moon, from full to new and back to full. I learned how bright the moon can be, illuminating my nighttime walks and the scorpion's nighttime hunts. I learned how poor the stargazing is when the moon is bright and how infinite the stars can be when the moon is dim or set. That one cycle of the moon helped me feel the rhythm of our planet and notice for the first time a celestial clock that moves at a human pace.

This section of Chapter 2 on natural navigation is an encouragement to learn and be curious about the natural world that the skills of this book will help you explore. Paying attention to the myriad details of your time in the wilderness, such as the phase of the moon, the length of the day, and whether the wildflowers or mushrooms are blooming, enhances your enjoyment and sharpens your situational awareness. For me, it makes me feel fully alive and keeps me safe.

Chapter 2 Conclusion

This chapter introduced map-only navigation, a fundamental skill for wilderness adventurers. We explored the concept of lines of position (LOPs), which serve as guides or references in the landscape and on the map. We examined physical LOPs, such as trails, ridges, and waterways, and learned how to identify and utilize them for effective navigation. Additionally, we introduced instrument LOPs, which involve measurements taken with compasses, altimeters, or GPS.

We learned that physical and instrument LOPs allow us to determine our location on the map and make informed navigational decisions. We also explored the concept of handrails and backstops, two special LOPs that help us stay on track or provide guidance on when we have gone far enough. We discussed a useful technique called trail dead reckoning, to navigate along trails accurately with only a map and a watch using the relationship between distance, rate of travel, and time. We finished with an author-favorite look at natural navigation that keeps situational awareness high by paying attention to the movements of our celestial neighbors.

As we progress to Chapter 3, we will explore the compass, a valuable tool that complements both map and GPS navigation. We will learn how to measure and use bearings, and discover the concept of situational awareness—a crucial mindset for safe and effective wilderness travel.

Chapter 3

Meet the Compass

When I ask for directions,
please don't use words like "east."
—Anonymous

COMPASS SKEPTIC

Navigating the wilderness in this era of GPS digital precision might tempt a skeptical explorer to consign the compass to the depths of their backpack. It's easy to dismiss the compass as a cumbersome relic, especially for those eager to dive straight into the digital realm of GPS technology. Yet, this skepticism overlooks a counterintuitive truth—the marriage of the compass and GPS transforms the former from an occasionally referenced tool to a continually consulted ally to our GPS.

Today's phones, our primary GPS device choice, have coaxed us into embracing expensive, fragile devices that leave us one slip away from navigational disarray. In striking contrast is my trusty first compass, a 1970 Silva Type 342, as it sits on my desk, steadfastly pointing north.

Granted, compasses lack the user-friendly interface of a well-prepared GPS with a "you are here" arrow on a relevant map. However, operating as a stalwart partner alongside your GPS device, the compass will help maintain your situational awareness and keep you on course, all while your critical electronics are safely stowed.

So, let's delve into the enduring relevance of compasses and their harmonious partnership with GPS. For the moment, take a leap of faith and consider keeping this 1000-year-old, battery-free device ready to guide your footsteps. It is fast, dependable, and keeps both hands free as you navigate from one intermediate waypoint to the next.

INTRODUCTION

KEY TOPICS
COMPASS BASICS
COMPASS MECHANICS
MEASURING & USING BEARINGS
SITUATIONAL AWARENESS

Here, we introduce you to the second of our five navigational tools, the compass. In easy terrain, a physical map and keen observation are the only tools needed to navigate, as we covered in Chapter

2: Map-Only Navigation. When the terrain becomes complicated or the visibility becomes more challenging, the compass is your steady friend, ready to reliably point to north and measure angles or bearings from north.

We will briefly describe the mechanics of compasses, typical compass types, their features, and how to use them for three tasks:

- Orienting the map to north.
- Answering the question, “Where am I?”
- Answering the question, “What is the bearing to my target?”

MEET THE COMPASS

While we think of a compass as a magnetic needle that freely rotates on a tiny spindle, today’s compasses also take forms such as phone apps, smartwatches, or dedicated GPS devices. While all our navigational tools now come in various formats, try not to feel overwhelmed. You do not need them all. This book guides you toward assembling a navigational toolbox that makes sense for your adventures.

COMPASS CHOICES

While the lure of electronics is strong, my biggest surprise in learning modern wilderness navigation is that I now use my battery-free, analog baseplate compass at least one hundred times more often in the GPS age than before. Especially during off-trail trips where every step requires navigation, this trusty tool lives on a lanyard around my neck, safely under my shirt. I don’t feel the need for the extra accuracy a mirror provides, so I always carry an analog baseplate compass similar to Figure 3-1(a). Consider buying a global model if you travel to substantially different latitudes. See note under “Magnetic Dip” below.

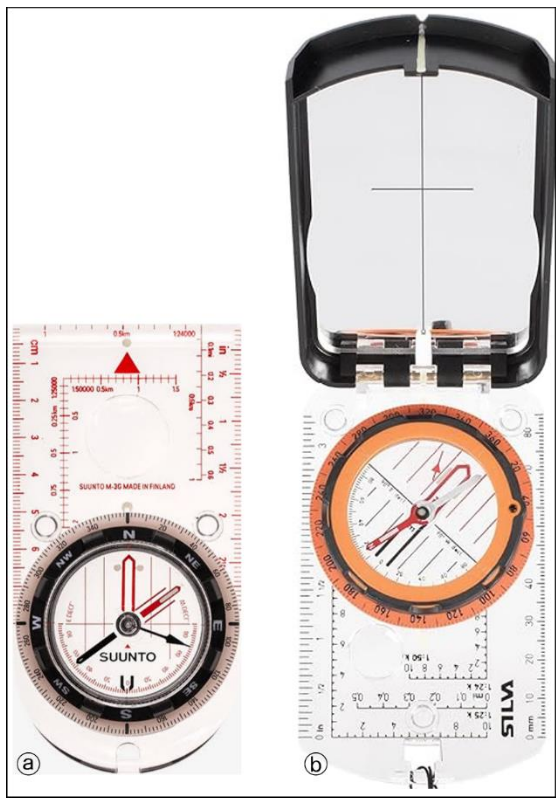


Fig. 3-1. *An analog baseplate compass with declination adjustment is highly recommended. The addition of a global needle is suggested. Example compass types: a, analog baseplate compass; b, analog baseplate compass with sighting mirror.*

Compass apps. Phones, dedicated GPS units, and smartwatches contain compass apps that compute direction in two ways. When stationary, these devices use a “compass chip,” meaning a 3-axis electronic magnetometer to determine north based on the local magnetic field, just like an analog magnetic compass. Since phones and dedicated GPS units know their location, some apps automatically adjust for local declination. When moving, these devices can determine the direction of travel using GPS satellites, independent of the Earth's magnetic field. See Figure 3-2.

While exceptionally reliable, accurate, and battery-free, analog compasses can be lost, forgotten, demagnetized, or subject to excessive magnetic dip. Phone compass apps are available for free or for a few dollars, so it is prudent to have at least one, primarily as a backup. GPS apps can give you a GPS bearing to your destination, but a compass or compass app is better at directing your next step in the physical world.

All current iPhones have a preloaded compass app. Compass apps are sufficiently accurate for taking and following bearings in the field. Some compass apps use the camera for sighting more accurate bearings. There are also augmented reality apps that overlay compass bearings, inclinometer, and location data over the phone's camera display. This allows for precise bearing measurements for navigation and slope incline measurements for skiers and avalanche terrain. Examples include Theodolite for iOS and Dioptra for Android. A significant shortcoming of compass apps is their inability to measure or plot bearings on a physical map, an important function covered below.

Most compass apps require regular calibration (although iPhones do not), especially after moving long distances and after extreme temperature changes. Calibration involves rotating the device in three directions sequentially. Some devices will remind you to calibrate and lead you through the process. Using a compass app is a slower process than using an analog compass. It puts your relatively fragile electronics at risk, but when combined with a phone's camera, it can be more accurate. A compass app constantly drains battery power that is better reserved for GPS and taking pictures. Therefore, always carry a standard analog compass, a device that will outlast all your electronics.

Watches. The altimeter-barometer-compass (ABC) watch was a significant category that GPS-enabled sports watches have mostly supplanted. In addition to timepiece functions, ABC watches contained a pressure-based altimeter that could alternatively be used as a barometer and a modestly accurate compass.

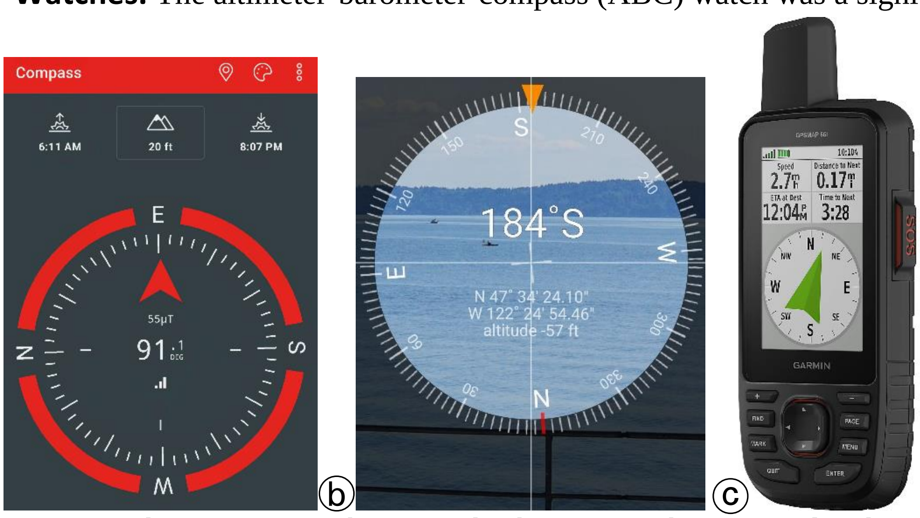


Fig. 3-2. *Digital compasses: a, phone app; b, phone app with augmented reality; c, dedicated GPS.*

GPS-enabled sports watches have many of the same navigation functions as a phone with the limitation of a small screen. These will be covered in Chapter 5.

ANALOG COMPASS FEATURES

Lodestone, a naturally magnetized iron ore, has been used in rituals dating back to the Han Chinese dynasty. However, in the 11th and 12th centuries, China and then the Western world began using lodestone to create compasses with iron needles. Today's magnetic compass still functions with a needle that pivots to align with magnetic north. Despite its ancient origins, a battery-free baseplate compass (also called an "orienteering compass") is an essential navigation tool. It can measure the angular bearing from true north in the field and function as a simple protractor to measure bearings on a paper map, something a compass app or compass without a baseplate cannot accomplish. Here are the essential features of a baseplate compass (see Figure 3-3):

- **Index line.** The index line marks where bearings are set and bearings are read. Some compass models have a back bearing line that can be confused with the index line. See Figure 3-4 below.
- **Orienting arrow ("shed").** The orienting arrow allows the compass housing to remain oriented to true north while the baseplate rotates to measure a compass bearing *in the field*. The orienting arrow on a declination adjustable compass can be rotated right or left independently of the rest of the housing to account for declination. The orienting arrow is familiarly known as "the shed." See Figure 3-15 below.
- **Orienting lines.** The orienting lines, sometimes called "meridian lines," allow the compass housing to remain oriented to map north while the baseplate rotates to measure a bearing *on a map*. This allows the compass to function as a protractor while ignoring the magnetic needle and the orienting arrow.
- **Declination scale.** The declination scale allows for accurately adjusting the orienting arrow on declination adjustable compasses.
- **Rulers and romer scales.** Rulers are used to

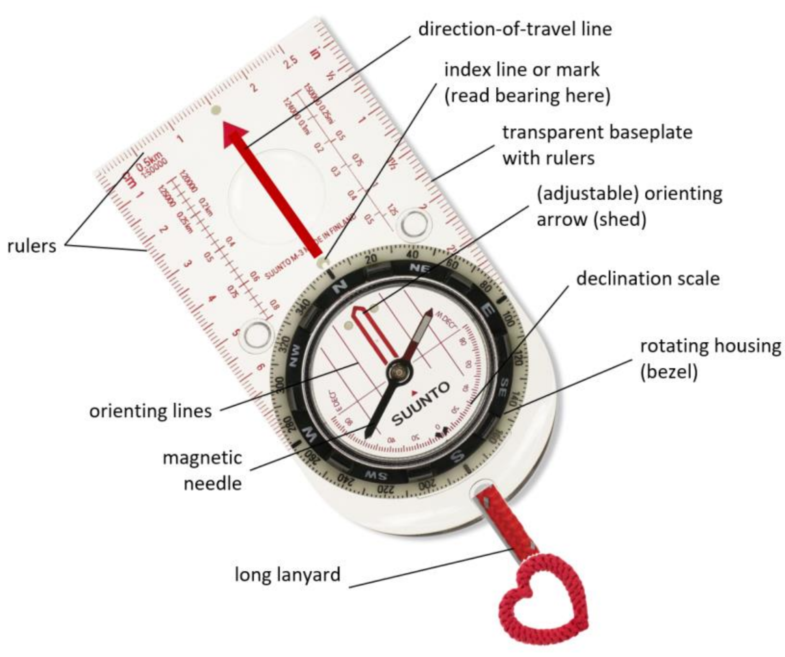


Fig. 3-3. *Features of a baseplate compass.* *[1) Note to the artist: Add a coil of lanyard ending in a heart. 2) Note to author: Add a note about how the heart connects to the human. Change to "Direction of travel arrow or line"]*

calculate distances on maps and measure tiny fish. Romer scales are used for interpolating UTM measurements on maps of particular scales. This is covered in Part II.

- **Base plate.** The base plate gives an extended edge for using the compass as a protractor on a map and for measuring bearings in the field.
- **Lanyard.** This cord measures distances on a meandering route or attaches the compass for quick access to a belt, pack, or neck. The latter should be worn inside a shirt for safety.
- **Direction of travel arrow or line.** The direction of travel arrow or line is used in the field for measuring or following a bearing. It is used on a map to indicate the direction away from the current location when measuring bearings.
- **Magnifying glass.** The magnifying glass is used to read the fine print and contour lines on a map.
- **Inclinometer.** The inclinometer, also known as a clinometer, is used to measure vertical angles such as the angle of a slope. See *inclinometer* below.

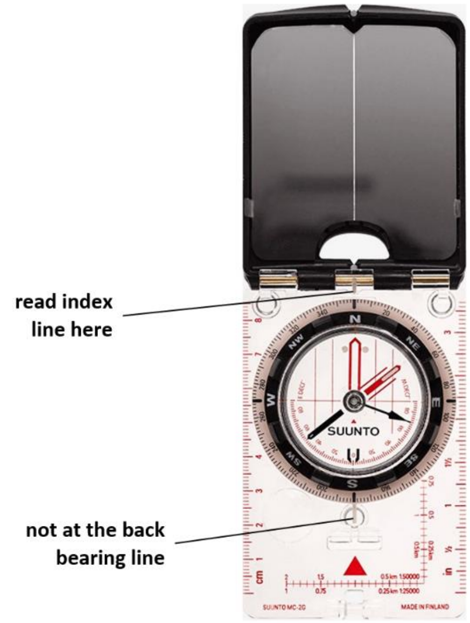


Fig. 3-4. *With many mirrored compasses, including the Suunto MC-2G, exercise caution to avoid confusing: a, the index line (where the bearing should be read); with b) the back bearing.*

- **Magnetic needle ("Red Fred").** The magnetic needle is a magnetized strip of metal that freely rotates on a low-friction pivot point and is balanced to counteract magnetic dip for specific regions. See *magnetic dip* below. The north-seeking end of the compass is usually painted red, while the south-seeking end is black or white.
- **Rotating housing or bezel with a 000° to 360° dial.** The housing holds the magnetic needle filled with a liquid (typically oil, kerosene, or alcohol) to dampen the movement of the needle. The housing perimeter is marked with bearings from 000°, or north, clockwise through 360 degrees back to north. Some compasses use other units of angle. The housing is rotated to measure bearings.
- **Mirror.** Note that baseplate compasses with and without mirrors are suitable for wilderness navigation. A mirror allows for more accurate bearings by allowing for more accurate alignment of the magnetic needle and the orienting arrow. A baseplate compass with a mirror is more expensive, more challenging, and heavier. The procedures in this book assume you are using a mirrorless compass. Except for aiming, both types use the same methods.

Caution regarding back bearing line. Note that the index line can easily be confused with the back bearing line on some compasses. Such a mistake would result in an error of 180°. A beginner using some mirrored compasses can easily make this error. The Suunto MC-2G in Figure 3-4, an otherwise great compass, is an example.

COMPASS MECHANICS

The motion of the molten iron core of our precious blue marble produces a strong magnetic field that shields us from the relentless solar wind of deadly atomic particles streaming from the Sun. Without this shield, life on this planet would not exist. A byproduct for us navigators is that a magnetized needle will accurately align with those magnetic fields. This is our magnetic compass.

Declination. Unfortunately, those magnetic fields do not flow in orderly meridians from the North Pole to the South; they meander as they flow between the magnetic poles. The magnetic north and south poles are in the neighborhood of the geographic poles, the ends of our globe's unvarying axis of rotation. As of publication, the magnetic north pole is about 1200 miles (1900 km) from the North Pole, and the magnetic south pole is approximately 1800 miles (2900 km) from the South Pole. Compass needles point *toward* the north and south magnetic poles but not directly at them. The compass needle aligns with the local magnetic field on its drunken walk between the magnetic poles. If you were to follow your compass needle toward your choice of the south or north magnetic pole, it would lead you there via a curving route, not by the shortest path.

The magnetic field at some locations, known as an *agonic line,* aligns with north, shown as the zero-degree declination line in the chart below. But almost everywhere, navigators must adjust for the angle of difference between magnetic north (the way the compass' magnetic needle points) and true north. This angle is known as *declination (see Figure 3-5).* All good topographic maps state the declination for the area covered as of their printing and, occasionally, the rate of change. There are many phone apps and websites (e.g., USGS.gov) to determine a location's declination. You can also measure declination directly; see inset Calculating Declination. I highly recommend purchasing a

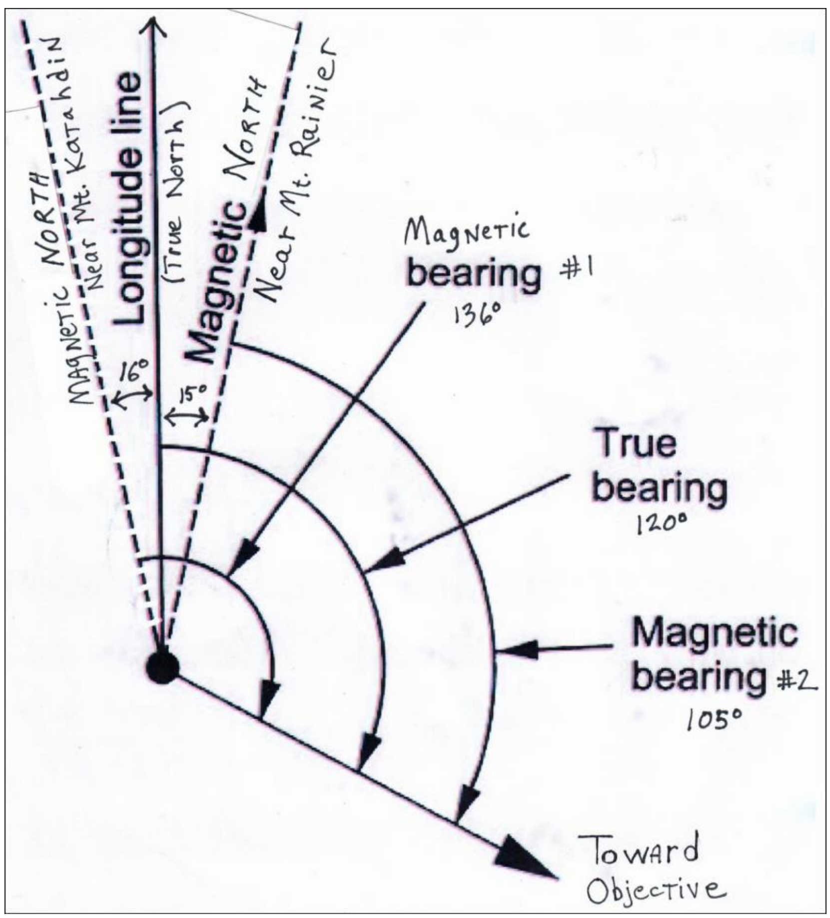


Fig. 3-4b. Measuring compass bearing on an objective with a true bearing of 120° from #1, Mt. Katahdin, or #2 Mt. Rainier.

compass that compensates for declination to avoid doing unnecessary mental arithmetic, an increasing challenge as you get tired. Orienteering competitions typically use maps printed using magnetic north for grid lines to avoid needing a declination-adjustable compass.

CALCULATING DECLINATION

It is instructive to compute declination for an area yourself. First, compute a GPS bearing (see Chapter 5) to an object or bit of geography in the distance that you can see and identify on a digital map. The GPS bearing will be true since it is computed using GPS and is unaffected by magnetic fields. Using a compass not adjusted for declination, measure a compass bearing to the same object or geography. The difference is your local declination.

This angle, declination, varies by geographic location and changes over time. For example, at Mt. Rainier, in 2024, a magnetic compass needle points too far east (clockwise) with such declination noted as +15°, or 15° east. At Mt. Katahdin, the northern terminus of the Appalachian Trail, a magnetic compass needle points too far west (counterclockwise) with a declination noted as -16° or 16° west.

Example. Figure 3-4b demonstrates the bearing you would measure on a non-declination adjustable compass on an objective with a true bearing of 120°. If you take a bearing on such an objective at Mt. Katahdin, the compass will read 136°. See magnetic bearing #1 in Figure 3-4b. If you take a bearing on such an object at Mt. Rainier, the compass will read 105°. See magnetic bearing #2 in Figure 3-4b. Figure 3-4(a) shows the direction the compass would point at Mt. Rainier with no declination adjustment. Figure 3-4(b) shows the direction the compass would point at Mt. Katahdin with no declination adjustment. Figure 3-4(c) shows that a declination-adjusted compass would point to true north at Mt. Rainier. This is true for anywhere the compass is adjusted for local declination.

The earth's 4.6 billion-year-old geology continues to evolve slowly. In the five decades since I was a Boy Scout in Seattle, the declination has decreased by one degree every seven years on average. That is a relatively normal rate of change. Most of the world, outside the Arctic regions, has a rate of change of 1° or less every six years.[11] The speed of change has been accelerating for unknown reasons, but the change is manageable. Figure 3-6 shows lines of equal declination for the continental US, southern Canada, and northern Mexico, including an agonic line where the declination is zero, and magnetic compasses point to true north. Figure 3-7 shows a similar declination world map.

Declination is also stable over reasonably long distances. The lines in Figures 3-6 and 3-7 note a change in declination or a "declination contour interval" of 2°. In the US, on average, you must travel about 100 miles (160 km) to have one degree of change in declination. In Europe, the distance is further. For most human-powered adventures, declination can be set once at the

[11] See the map called "Change in Magnetic Declination at 2020 from the World Magnetic Model" at https://www.ncei.noaa.gov/products/world-magnetic-model.

beginning of a trip.

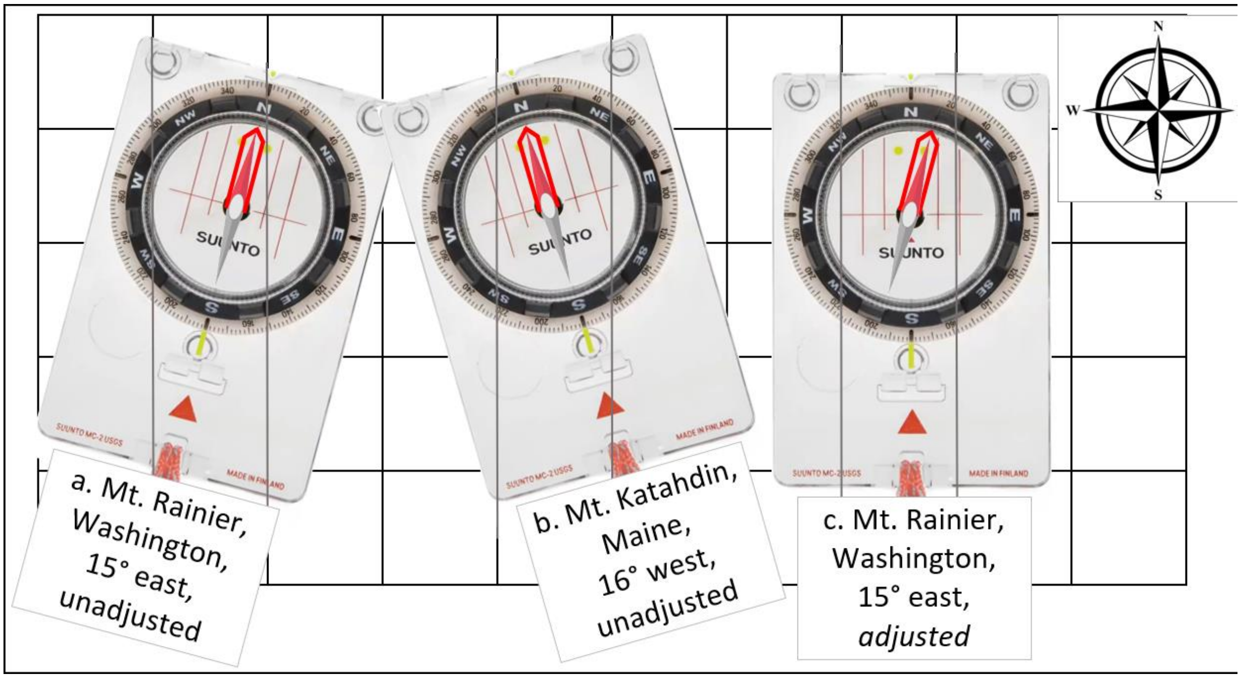


Fig. 3-5. *Illustration of how compass needles point in areas of different declination shown against map grid lines: a, Mt. Rainier with no adjustment for declination; b, Mt. Katahdin with no adjustment for declination; c, Mt. Rainier adjusted for declination on a declination-adjustable compass.*

Adjusting for declination. GPS bearings and map bearings are unaffected by magnetic fields and so are always based on true north. They require no adjustment. Compass bearings must be adjusted for declination before use unless you are close to an agonic line. There are three ways to adjust for declination.

- **The easy way.** Pay more to purchase a declination-adjustable baseplate compass. The orienting arrow on a declination-adjustable baseplate compass can rotate clockwise or counterclockwise, independent of the rest of the housing. This adjustable arrow is sometimes called a "declination arrow." This skews the orienting arrow to mitigate the magnetic needle's alignment with magnetic north. The example in *Figure 3-5(c)* shows how the orienting arrow has been rotated 15° clockwise (east) to mitigate the effect of the magnetic needle, which also points too far east by 15°. Such compasses can be used without further adjustment for declination, but see the caution below before purchase.
- **Another easy way.** If you find it necessary to use a non-declination-adjustable baseplate compass, you can create the same effect with a piece of tape. First, set a bearing equal to the desired declination. Now, put a narrow piece of Scotch tape on the bottom of your compass from the central hub to the direction of travel arrow or the north end of the compass. Draw a straight line on the tape from the hub to north with a permanent marker. This line will be visible from the top of the compass. Use this as an alternate orienting arrow. Use the compass as you would in #1.

Fig. 3-6. *Declination map of the continental US, southern Canada, and northern Mexico for 2020.* *[Insert map projected for 2030 that includes more of Canada.]*

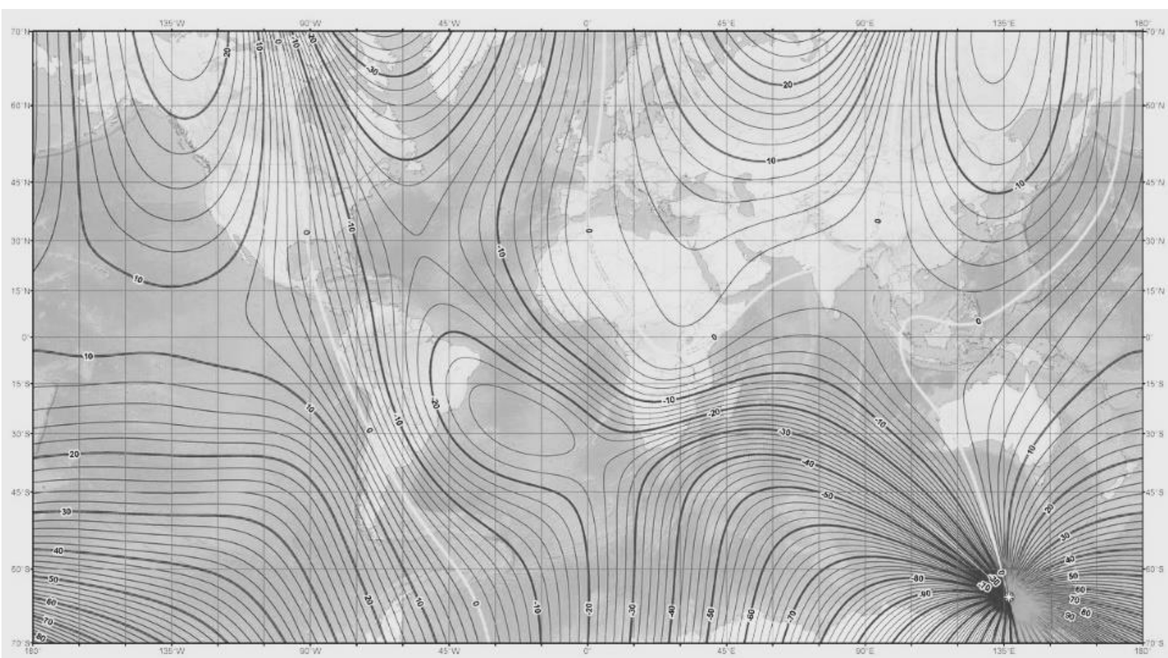


Fig. 3-7. *Declination map of the world projected for 2030.*
[Insert map projected for 2030 with larger numbers and the agonic lines highlighted.]

- **The math way.** Adjusting for declination mathematically is confusing for most of us. When you add the fatigue of a long day, you have an increased chance of a navigation error with possible unfortunate consequences. To accomplish the mathematical feat,remember that east declinations are positive numbers, and west declinations are negative numbers. For example, the local declination at Mt. Rainier in Washington State is currently 15° east (+15°), and the local declination at Mt. Katahdin in the state of Maine is currently 16° west (-16°).

ADJUSTING DECLINATION BY MATH

This mnemonic may help you remember how to adjust a bearing measurement made on a map to use (follow) with a compass in the field or a bearing measurement made in the field to use (plot) on a map. This method works if you follow the convention that east declination is a positive number and west declination is negative:

FIELD TO MAP→ADAPT (ADD)

MAP TO FIELD→YIELD (SUBTRACT)

  - **Map Bearing to field: subtract.** To convert a map bearing (i.e., one measured on a map) to follow in the field using a non-declination-adjustable compass, you must *subtract* the declination from the map bearing.

    Rainier example: A map bearing for north measured using any compass as a protractor is 000° or 360° since we ignore the magnetic arrow. To determine the compass bearing to follow with a non-adjustable compass near Mt. Rainier, subtract 15° from the map bearing (360° - 15° = 345°). If you follow a bearing of 345° on a non-adjustable compass near Mt. Rainier, you will travel exactly north.

    Katahdin example: To determine the compass bearing to follow with a non-adjustable compass near Mt. Katahdin, subtract (-16°) from the map bearing (360° - (-16°) = 16°). If you follow a bearing of 16° on a non-adjustable compass near Mt. Katahdin, you will travel exactly north.

  - **Compass bearing to map: add.** To convert a compass bearing (i.e., one taken in the field) measured using a non-declination-adjustable compass to plot on a map, you must *add* the declination to the compass bearing.

    Katahdin example: If you measure a compass bearing with a non-adjustable compass while facing exactly north near Mt. Katahdin, your compass will read 16°. To plot this on a map, you must add the local (negative) declination: 16° + (-16°) = 000° or 360°. If you plot 000° or 360° on a map, you will have a direction of travel that is precisely north.

    Rainier example: If you measure a compass bearing with a non-adjustable compass while facing exactly north near Mt. Rainier, your compass will read 345°. To plot this on a map, you must add the local declination: 345° + 15° = 360°. If you plot 360° (or 000°) on a map, you will have a direction of travel that is precisely north.

Caution. Most compasses have a *fixed declination correction scale* but are not declination-adjustable. A *fixed declination correction scale* attempts to assist with the math required in number 3 above, but it still requires math. By contrast, the orienting arrow on a declination-adjustable baseplate compass rotates to mitigate any need for doing math. See Figure 3-8.

Magnetic dip. The compass needle aligns itself with the local magnetic field. Unfortunately, the Earth's protectant magnetic fields not only don't point directly north-south, but they also are not level except near the equator. At the extreme, the magnetic field is vertical at the magnetic poles. A vertical magnetic field is the definition of a magnetic pole. In between the polar extremes, compass manufacturers typically compensate for this magnetic dip by putting tiny weights on the compass needle. If they did not, the compass needle would be sufficiently out of level in many locations that it would drag on the compass housing, making it difficult or impossible to use. But compass dip varies by how far north or south it is, so compass manufacturers divide the world into three to five zones and sell differently weighted compasses in each.

Fig. 3-8. *Using a tool to adjust declination on a declination-adjustable compass.*

World travelers wishing to avoid owning a collection of compasses can, for about $20 extra, purchase a single "global" model that cleverly separates the magnet from the needle, allowing it to work worldwide. Some global compasses simply create a thicker housing to give the magnetic needle more room to tilt. Compass apps do not suffer from magnetic dip issues.

Other compass issues. The author has seen an entertaining grab bag of compass issues in his classes. We have seen batches of new compasses with significant errors and old compasses with huge errors. Much of the metal in our lives is ferromagnetic (typically iron or nickel), which affects how a compass points. Some student struggles are caused simply by an ice axe, belt buckle, watch, phone, lanyard clasp, magnetic hydration hose, car hood, and even heated gloves. In addition, certain rocks may contain sufficient iron to cause false compass readings. If you are getting strange results, look for these causes.

Inclinometer. The occasionally useful compass inclinometer can measure slope angles. Some compasses feature a non-magnetic needle that dangles toward an additional slope angle scale inside the compass housing. To determine the slope angle, set the bearing to west (270°)[12] at the index line, align the long edge of the compass with the slope to be measured, and read the slope angle on the additional scale. The inclinometer has yet to find much use in backcountry navigation. It seems that using an inclinometer to measure the slope angle in front of you for comparison with a topographic map would be helpful. Instead, visually assessing slopes as flat,

[12] Left handed people may prefer setting the bearing to east (90°) at the index line.

moderate, steep, very steep, or cliffy is usually sufficient.

By contrast, those practicing winter sports, including backcountry skiers, climbers, and scramblers, rely on clinometers since the highest avalanche risk happens on slope angles between 30° and 45°. They have found inclinometer apps are easier to use and more accurate than the tiny dangling needle of a compass inclinometer.

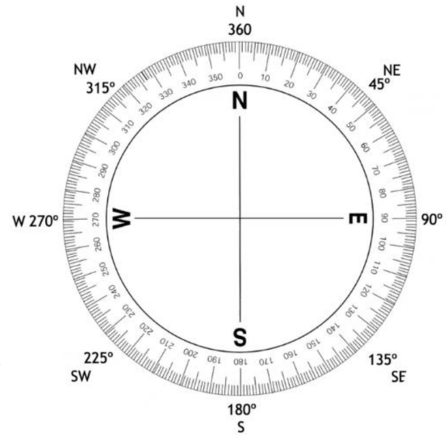


Fig. 3-9. *Compass rose divided into 360 degrees.*

Purchasing a compass. I strongly recommend buying a good quality declination-adjustable baseplate compass, but see the caution above. A global compass is recommended to counteract excessive compass dip for those traveling to substantially different latitudes. A mirror is typically not required but allows more accurate readings. Compasses with a tiny tool connected to the lanyard are easier to adjust for declination than the tool-free variety. Before or soon after purchase, test the compass for accuracy against a GPS bearing, make sure the needle is level and swings freely, and that the housing moves smoothly and has no bubbles in the fluid. See Table 3-1 for a summary of features to consider when purchasing a compass. Be wary of deals on compasses designed for other latitudes.

TABLE 3-1. COMPASS FEATURES

RECOMMENDED	AVOID OR UNNECESSARY
• Clear baseplate • Declination adjustable • Lanyard • Global model (see note in the text above)	• Nonadjustable declination scale • Clinometer • Mirror • Cheap novelty, “zipper pull,” and “survival” compasses

PUTTING THE COMPASS TO WORK

BEARINGS

The North and South Poles are where our spinning globe’s axis of rotation meets the surface. Whenever we point north or south, we point toward a physical spot north of Canada or in Antarctica. East and west form a line perpendicular to the north-south line. Whenever we point east or west, we are not pointing toward anything specific on Earth but at a 90° angle from the north-south line. This starts to help in giving directions. We could say, “Cross the river at the bridge and head east for 1 km.” But pretty soon, we would want to refer to directions other than north, east, south, or west. We would then need terms for northeast, southeast, southwest, and northwest. But then, the need for more precision would become apparent, and instead of continuing with the confusing "north by northeast" and so on, we would use bearings.

360 Bearings. We divide the circle into an easily divisible 360 parts or degrees from a convention dating back to the Babylonians. Also, by convention, we call true north zero degrees (000°) and proceed clockwise around the circle, noting that east is 90°, south is 180°, west is 270°, and north is 360°. We can refer to north as either 000° or 360°, although the latter is clearer when spoken. See Figure 3-9.

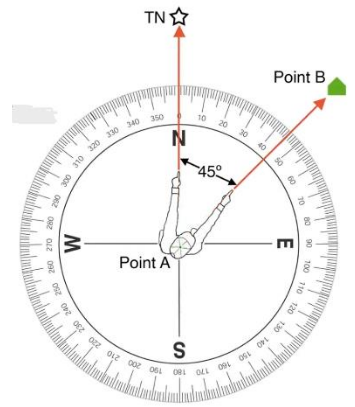


Fig. 3-10. *Compass rose showing a bearing of 45 degrees.*

Now, we have a precise way to state a direction or bearing from one place to another. We can say, "Cross the river at the bridge and head on a particular bearing for 1 km." Figure 3-10 illustrates a bearing from Point A to Point B of 45°.

Bearing measurements and uses. As a reminder of the subject of Chapter 2, we can often travel using terrain recognition, using only our map, spotting LOPs on the map and in the field to guide our way. When we add a compass, we have bearings, for which we have three sources and three uses. Figure 3-11 summarizes the sources and uses for bearings.

Tools to measure bearings. We have three tools to measure bearings: GPS devices, maps, and compasses. Our three bearing measurements are denoted by the numbers 1, 2, and 3:

1. **Measure a GPS bearing.** A GPS bearing is measured using a GPS device, the subject of Chapter 5. This will be our most common source of bearings during wilderness navigation.
2. **Measure a map bearing.** We can measure a map bearing on our map using our baseplate compass as a protractor. This method is surprisingly fast and keeps our situational awareness high.
3. **Measure a compass bearing.** We can also measure a compass bearing in the field using, of course, our compass.

→ **Tools to use bearings.** We have the same three tools to use these bearings. They are denoted by the letters a, b, c:

a. **Follow a GPS bearing.** Any of our three bearing measurements can be input into a GPS. Then, the "Go-To" function can continuously point the way directly to our objective with a simple arrow that continuously adjusts when you don't travel in a straight line. This allows us to use "live navigation" to move toward the target.

b. **Plot a map bearing.** GPS bearings or compass bearings can be "plotted" on the map to identify a distant, visible object on the map.

c. **Follow a compass bearing.** A compass is the most common way to use a bearing in the field. Any of our three types of bearing measurements can be used with a compass in the field to guide our footsteps.

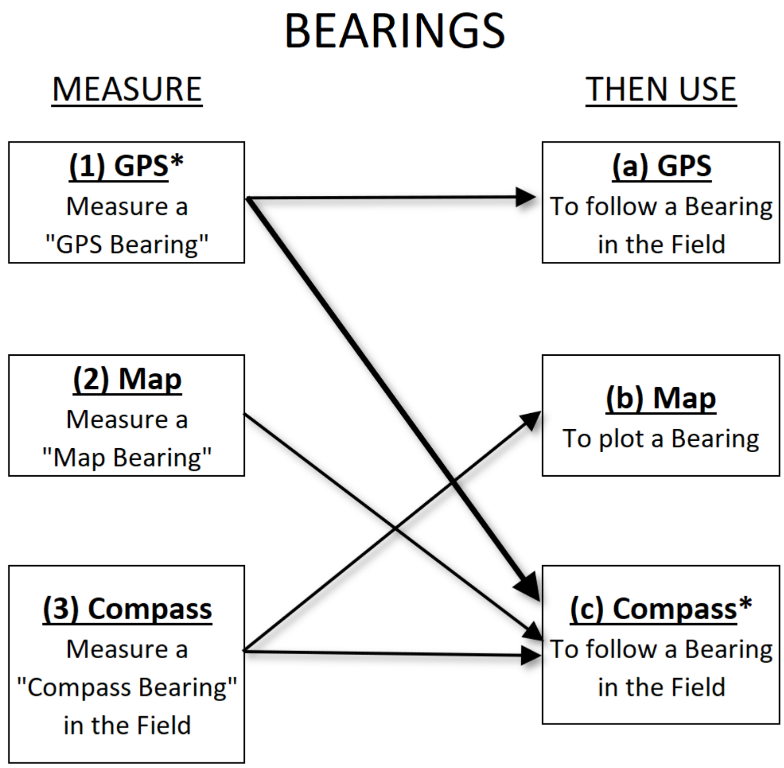


Fig. 3-11. *Measuring and then using bearings.* *First, bearings are measured (1) with a GPS device, (2) on a map, or (3) using a compass in the field. Then, these bearings are used with either (a) a GPS device to follow in the field, (b) a map to plot, or (c) a compass to follow in the field. Asterisks (*) and heavy arrows (→) denote the primary methods used to measure and use a bearing.*

HOW TO MEASURE BEARINGS

The section above lists the three tools for measuring a bearing and the three for using bearings. This section details how to measure bearings. Remember that measuring a bearing merely gives you an angle in degrees measured from true north from point A to point B. It has no practical meaning until we put it to use, which we will do in the section "Then→How to Use Bearings." Measuring and then using bearings are the two halves of a single process whose purpose is to find our location or guide our next step.

1) MEASURING A GPS BEARING.

As our most common source of bearings, a GPS bearing is measured using a GPS device, the subject of Chapter 5. Remember that the device recommended for most situations is a phone app

Fig. 3-12. *The mirrored compass (a) is reimagined (b) with only the parts essential for measuring or plotting bearings on a map.*

[Artist, please 1) draw the lanyard with a small stick figure swinging from the lanyard; 2) do not draw the text at the bottom of the compass or the circles at the top; 3) add labels with arrows for: the two straight edges; the rotating housing with orienting lines and bezel marked in degrees; and the index line for reading bearings.]

such as Gaia GPS or CalTopo.

2) MEASURING A MAP BEARING.

We *measure* map bearings on our map or *plot* previously measured bearings onto our map by using our baseplate compass as a protractor. Using our baseplate compass as a protractor is surprisingly fast and keeps situational awareness high. When using a compass with a map, we ignore the compass' magnetic needle, orienting arrow, inclinometer, declination scale, and occasionally helpful measuring scales. Measuring a bearing using our compass as a protractor is covered here. Using a compass as a protractor to plot a bearing onto a map is covered below under "Using a bearing by plotting it onto a map." We only use a magnetic needle with a map when we "orient the map" in the field with north, a process we cover below in the section "Orienting the Map to North."

The typical mirrored compass depicted in Figure 3-12(a) has been simplified and stripped down to the components essential for measuring or plotting bearings on a map. The reimagined minimalist version in Figure 3-12(b) is now essentially a protractor with only an index line (positioned above the "N"), straight edges, and a rotating housing with its orienting lines and bearings marked on the bezel.

Why measure a map bearing?

The necessity to measure a "map bearing" (the angular direction from one point to another on a map) arises when you need the direction of travel or the orientation to a specific landscape feature. For example, suppose a hiker wishes to reach a lake. In that case, they can measure the map bearing from their current or prospective location, providing them with the precise direction to reach the destination. This process is valuable for planning a route that navigates around potential obstacles, ensuring an efficient journey.

Consider a backpacker intending to reach a mountain peak but faced with an obstructive swamp. Using their map, the backpacker can determine a route that circumvents the swamp, facilitating an efficient journey. Similarly, in challenging conditions such as navigating through a foggy forest, a hiker can measure a map bearing to guide them toward a reliable backstop, such as a nearby road or trail, ensuring a safe exit.

Furthermore, for those traversing along a physical LOP like a complex ridge or a forked trail, measuring its map bearing helps keep the walker on course. It allows them to determine where to turn onto a new LOP. For example, if you are hiking due south (180°) and the bearing of an upcoming trail is 85°, the compass will help you find it. Although there could be more than one trail that heads off at 85°, the compass will help you eliminate all the trails not on this bearing.

Steps to measure a map bearing.

Step 1: In Figure 3-13, identify two known points on the map: your current (or prospective) position (point A) and the point you want to measure to (point B), which could be a destination, a point along a Line of Position (LOP), or a backstop. To determine the angle in degrees from true north, essential for your navigation objectives, follow these steps:

- Start with the map positioned in front of you, ensuring that north is at the top, away from the navigator.
- Place your compass on the map, aligning either of its long, straight edges with points A and B. It's crucial to position the lanyard end of the compass where you are (or plan to be) and the other end at your objective. Use the heart symbol in Figure 3-12 as a memory jog for which end to place yourself. Refer to the inset "180° Errors" for additional guidance.

Step 2: While holding the baseplate stationary:

- Touch one of its edges to points A and B.
- Rotate the compass housing until the "N" is pointed to the north (top) end of the map and the orienting lines are parallel to the north-south (up and down) grid lines on the map.
- Disregard features such as red, the shed, and other compass details.
- The bearing to the objective (point B) can now be read at the index line, as illustrated in Figures 3-3 and 3-4.

Shortcut: Once the bearing is set at the index line, the compass can be used to follow the bearing from point A to point B without further adjustment. This shortcut streamlines the navigation process and ensures accuracy in following the designated bearing.

180° ERRORS

When measuring and plotting bearings on a map, there are two easy ways to make a 180° error.

1) Erroneously put the lanyard end of the compass at your destination instead of at your location.

2) After correctly putting the lanyard end of the compass at your location, you erroneously rotate the housing so that south is pointed to the north end (top) of the map.

If you estimate the result before measuring or plotting, these errors can be avoided.

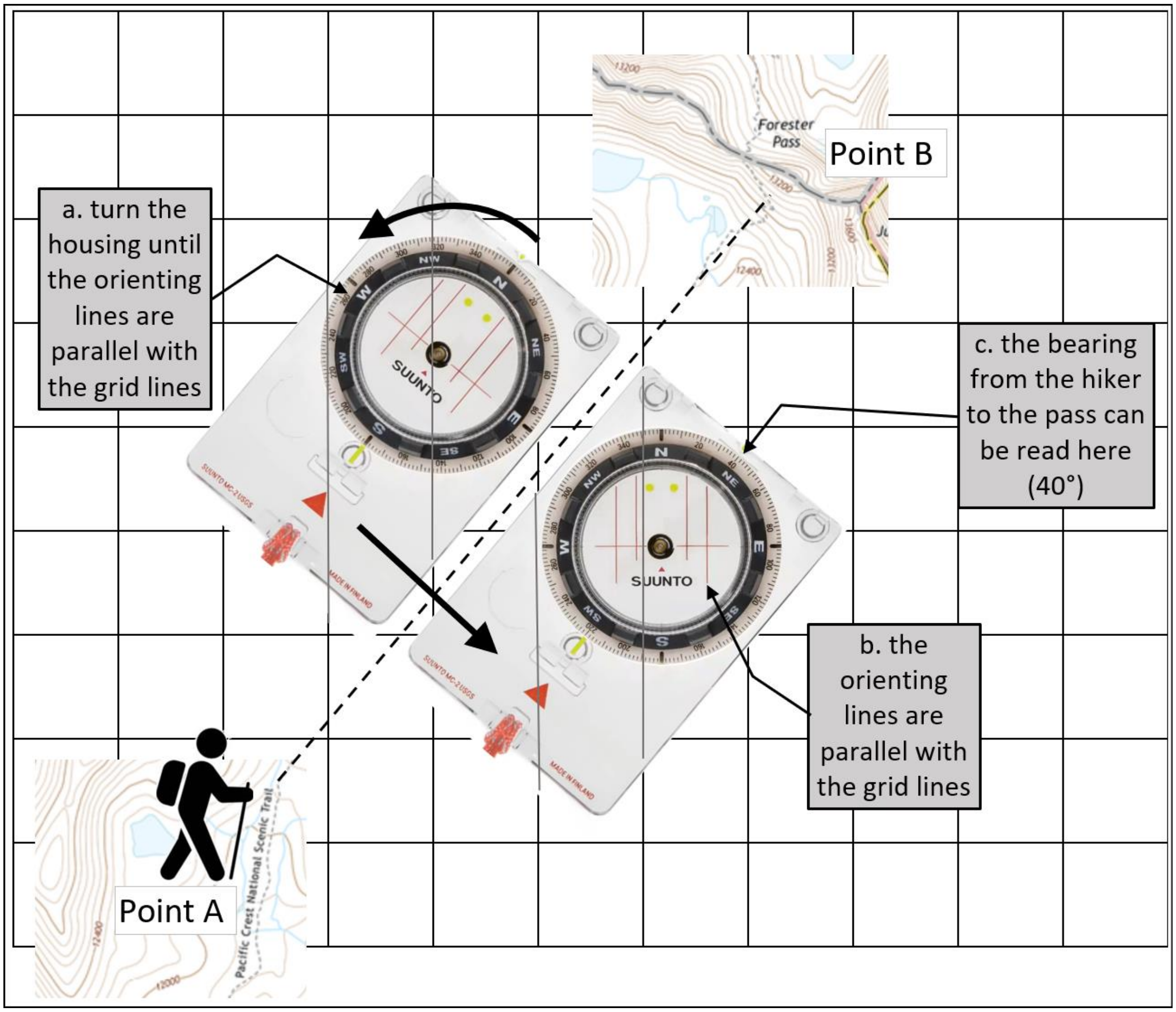


Fig. 3-13. *Measure a **map bearing** from known point A to known point B: (a) orienting lines not parallel with the grid lines; (b) orienting lines now parallel with the grid lines; (c) the bearing can be read at the index line*. {Redraw this Figure using a complete map.}

3) MEASURING A COMPASS BEARING.

Measuring a compass bearing involves using a baseplate compass to measure, by hand and eye, the direction from your current position to a visible object in the landscape (see Figure 3-14). This discussion assumes using a baseplate compass, adjusted for local declination.

Why *measure* a compass bearing?

The need to measure a compass bearing arises only in the field, allowing you to determine the direction toward a visible feature in the landscape:

- Compass bearings are primarily measured to create an Instrument Line of Position (LOP) to follow on its own or to aid in following an existing LOP, such as a trail or ridge.
- Compass bearings are occasionally measured to be used with other LOPs to pinpoint your

location on a physical map.
- Compass bearings are occasionally done to identify a visible object, such as a peak or pass.

In the upcoming section, "How to Use Bearings," we will explore the many ways to *use* bearings with the compass.

Note: Measuring compass bearings is not feasible in low-visibility conditions; in high-visibility conditions, there might be a lack of useful objects.

RED IN THE SHED

The ability to line up the compass' usually red north-seeking end of the magnetic needle with the adjustable orienting arrow—or put "Red in the shed"—is an essential skill. The pointed end of the orienting arrow can be envisioned as a tall, narrow "shed" with a pitched roof.

When ***measuring*** a bearing, the housing is turned until Red is in the shed.

When ***using*** a bearing, the housing is adjusted to the previously measured bearing, and then the entire compass is turned until Red is in the shed.

Steps to measure a compass bearing with a baseplate compass. This is accomplished in three steps:

Step 1: Decide on the object in the landscape for which you wish to measure a bearing. The choice of object will depend on the intended use and what is visible.

Step 2: With the lanyard pointed toward the navigator and the direction of travel arrow pointed at the object, hold the mirrorless baseplate compass as in Figure 3-14(a) or the baseplate compass with a mirror as in Figure 3-14(b). Ensure the compass is level and the direction of travel arrow is pointed straight ahead toward the object.

Step 3: While holding the baseplate stationary and toward the object, *rotate the housing until the orienting arrow (shed) is aligned with the compass needle's north-seeking (red) end.* Red is now in the shed. The compass bearing of the object can now be read at the index line. See Figure 3-15 and 3-16.

Steps to measure a bearing with a digital compass. This is accomplished in three steps:

Step 1: Decide on the object in the landscape, as above.

Step 2: With a digital compass app open, hold the phone at arm's length with two hands and the screen toward you; turn your entire body as a unit until the object appears on the display and aligns with the crosshairs or reticle, as in Figure 3-14(c).

Step 3: The measured bearing now appears on the screen.

Fig. 3-14. *Measuring a compass bearing in the field: a, with a mirrorless baseplate compass; b, with a baseplate compass with mirror; c, with a compass app using a phone's zoom camera.*

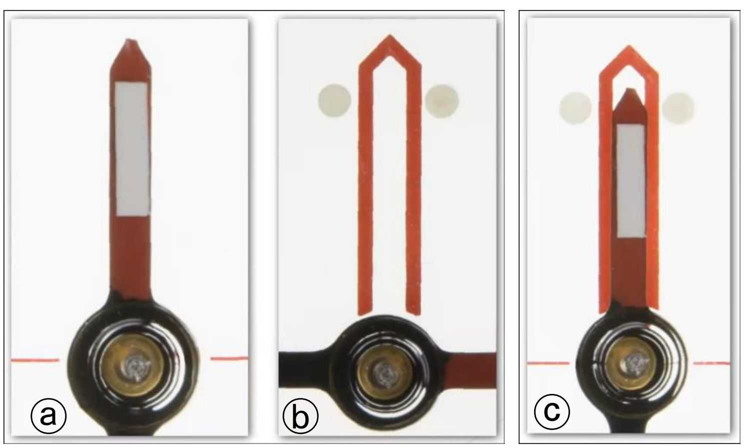


Fig. 3-15. *Aligning a compass' magnetic needle with the orienting arrow: a, magnetic needle (red); b, orienting arrow (shed); c, red is in the shed!* *{thank you, Otto!}* ***{REDO THIS DIAGRAM: Note that the housing is turned to put Red in Shed when MEASURING a bearing, and the entire compass is moved with the body as one unit when setting/using a previously measured bearing!!}***

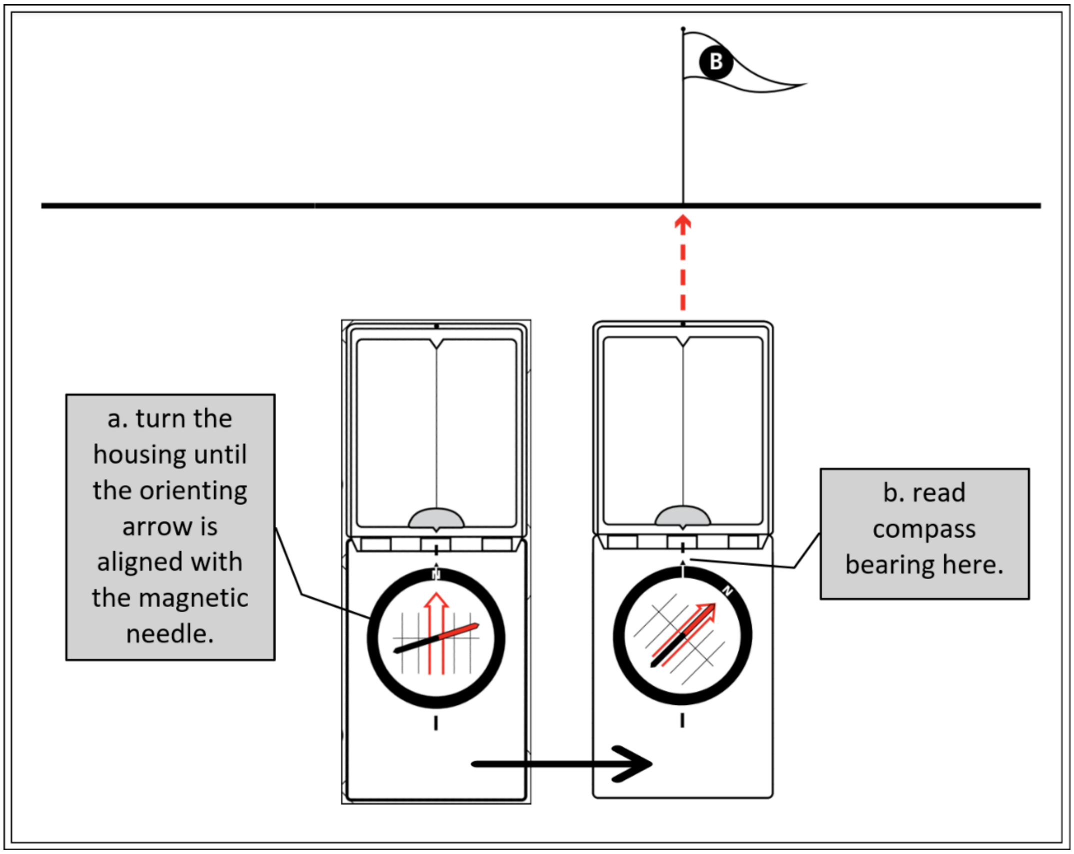


Fig. 3-16. *Measuring a compass bearing in the field: a, with the compass held level and the direction of travel arrow pointed straight ahead toward the object, rotate the housing until the orienting arrow (shed) is aligned with the compass needle's north-seeking (red) end; b, the compass bearing can now be read at the index line. COMMENT.*

[Artist note: 1) The compass needle should not move; they should be precisely parallel; 2) Draw the compass without a mirror; 3) Draw a bit of the lanyard as a subtle reminder; 4) Replace the flag with a mountain pass; Re-Do this with a non-mirrored compass. Less tall so fits on page. ***TRAVIS: I would also suggest showing the mountain pass for image A, because right now, the images suggest you are turning to go from not pointing to your destination to pointing to your destination, and that's the not what the captions are describing.****]*

THEN→HOW TO USE BEARINGS

The section above lists the three methods for *measuring* a bearing. This section details the methods for *using* bearings. It is worth repeating that measuring a bearing merely yields an angle in degrees measured from true north. Here, we use the bearing, giving it practical value. Measuring and using bearings are the two halves of a single process. Here, we complete the process to find our location or guide our next step.

At this point, it is worth reviewing Figure 3-11, which illustrates using GPS, maps, and compass for measuring and then using bearings, with the most common pairs noted with arrows. Here, we will discuss using bearings with the same three devices but realize that the measurement can be done with a GPS device, a map, or a compass.

1) USING A BEARING WITH GPS.

Using a GPS device to follow a bearing is a commonly used method. It is especially suitable for well-marked trails and hikers new to GPS technology. It is flexible since the bearing will adjust to your target when you drift laterally, intentionally, or unintentionally. While convenient, this approach puts your electronics at risk, drains your battery, requires the continuous use of one of your hands, and hinders situational awareness. It is best for short-term use in more casual situations. This method is discussed at length under "On-trail GPS Navigation" using only a GPS device in Chapter 5.

2) USING A BEARING BY PLOTTING IT ONTO A MAP.

Drawing a line onto a map with the line rotated clockwise a certain number of degrees (the bearing) from the vertical (north) is known as "plotting" a bearing onto a map. While you do not always need to draw the line on the map, we will illustrate plotting a bearing with an actual line. In the illustration below, point A is where we are or plan to be. Point B is our point of interest, typically where we want to go. When we "plot" a compass bearing (previously measured in the field) from point A to point B, we know the location of point A or B but not both. Again, we will use our compass as a protractor, reimagining it as in Figure 3-12(b).

Steps to plot a bearing when the current location, point A, is unknown. This is accomplished in two steps:

Step 1: Adjust your compass to the compass bearing previously measured in the field (it may still be set to this bearing). Set your compass on the map so that one of the corners farthest from the lanyard sits on top of the measured object (B).

Step 2: Without changing the bearing at the index line, rotate the entire compass around point B until the "N" is pointed to the north (top) end of the map and the orienting lines are parallel with the north-south (up and down) grid lines on the map. We have ignored red, the shed, and all the other compass features. Now, draw a line (real or imaginary) from the measured object (B) back along the long, straight edge of the compass. Point A is somewhere on this LOP. See Figure 3-17. A second LOP is needed to locate Point A precisely, as covered in Chapter 2.

Now that you have plotted the bearing from a known object to your unknown location, you have a useful LOP. Instead of being anywhere on the map, your position lies somewhere along this line.

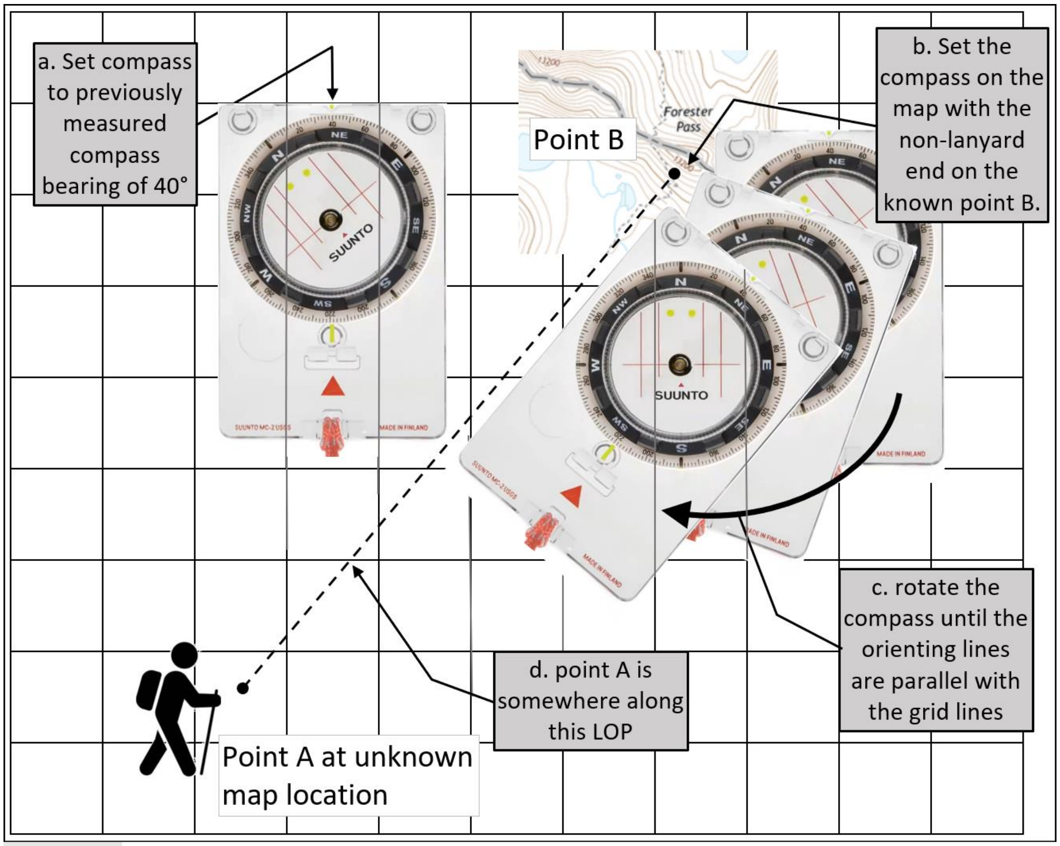


Fig. 3-17. *Steps to plot a previously measured 40° bearing to known point B on a map: (a) set compass to previously measured bearing (40°); (b) set compass edge on known point (B); (c) Rotate compass; (d) point A is somewhere along this LOP.* *{ TRAVIS: Same comment as above with this diagram, the read bearing here mark is kind of on the wrong part of the compass. }* ***JOHNG: I find this diagram quite confusing because with a simple baseplate compass, the "read bearing here" is not on the edge of the compass but rather in the the middle. Seems like the compass in both these diagrams should be rotated 180°.***

Steps to plot a bearing when the measured object, point B, is unknown. This is accomplished in two steps:

Step 1: Adjust your compass to the compass bearing previously measured in the field (it may still be set to this bearing). Set one of the corners closest to the lanyard on top of your current (or planned) location (A).

Step 2: Without changing the bearing at the index line, rotate the entire compass around point A until the "N" is pointed to the north (top) end of the map and the orienting lines are parallel with the north-south (up and down) grid lines on the map. We have ignored red, the shed, and all the other compass features. Now, draw a line (real or imaginary) from your current location (A) along the long straight edge. Point B is somewhere on this LOP, and since it was visible when you measured the compass bearing, you should be able to identify point B on the map. These steps are similar to those shown in Figure 3-17.

Only rarely do we need to plot a bearing *from* a known location. One example is the need to confirm your current location, even when you have a map and GPS. To do this, compare a bearing to a landmark to the bearing on the map. If the bearings match, you can be confident you know your location. It's also handy to plot bearings to distant peaks for identification.

Triangulation Failure. Triangulation, also known as "resection" by military folks, is a technique where two or more compass bearings are measured from a position and then plotted onto a map to determine the intersection, which reveals the position on the map. Although this technique was once emphasized in scout, military, and wilderness navigation training due to limited alternatives, its now-overrated importance persists despite two potential points of failure:

1. Poor visibility, such as in forests, fog, or at night, makes it difficult to identify objects from which to take bearings.
2. Visible objects may not be correctly identifiable on the map or could be too distant to be included on the map.

Neither of these failure points can be present to use triangulation effectively for establishing a location on a map. Alternatively, it is more likely that a single bearing can be used in conjunction with another Line of Position (LOP) to determine location.

In addition, the greatest accuracy is achieved when the compass bearing or LOP angles cross at 90°. Ideally, aim for an angle that is between 60° and 120°. Angles between 30° and 60° (or between 120° and 150°) can be acceptable. Avoid angles less than 30° or greater than 150° since the errors become problematic. Establishing your position by using two or more compass bearings is a rarely used technique. Establishing your position using two or more LOPs, one of which may be a compass bearing, is a practical and often-used technique.

3) USING A BEARING IN THE FIELD WITH A COMPASS.

The need to follow a bearing in the field with a compass arises when you have previously measured the bearing (typically using GPS or occasionally a map or compass) to your next objective and wish to follow this instrument bearing with your compass. Following the bearing of a physical LOP, such as a ridge or trail, can help keep you on course. When a suitable LOP is unavailable, you may need to follow a bearing using the techniques known as "live navigation" or "dead reckoning," which are covered below.

Steps to follow a bearing in the field with a *baseplate* compass. This is accomplished in two steps:

Step 1: Set the previously measured bearing at the compass index line and hold the compass as in Figure 3-14 (a) or (b) above.

Step 2: Without rotating the housing (i.e., do not change the previously measured bearing), rotate your body and compass together as a unit until the direction of travel arrow aligns with the compass needle's north (red) end until Red is in the shed. The direction of travel arrow is directly pointed toward your next objective. See Figure 3-18.

Follow a bearing in the field with a *digital* compass app. This is accomplished in two steps:

Step 1: If using a standard digital compass that emulates a baseplate compass, similar to Figure 3-2(a), hold the phone as you would a compass in Figure 3-14(a). If using a digital compass with augmented reality, similar to Figure 3-2(b), hold the phone at arm's length with two hands and the screen toward you.

Step 2: Turn your entire body as a unit until the previously measured bearing appears on the display. When using a standard digital compass, any object that aligns with the direction of travel arrow lies on the path of the previously measured bearing. When using an augmented reality compass, any object that aligns with the crosshairs or reticle (as in Figure 3-14(c)) lies on the path of the previously measured bearing.

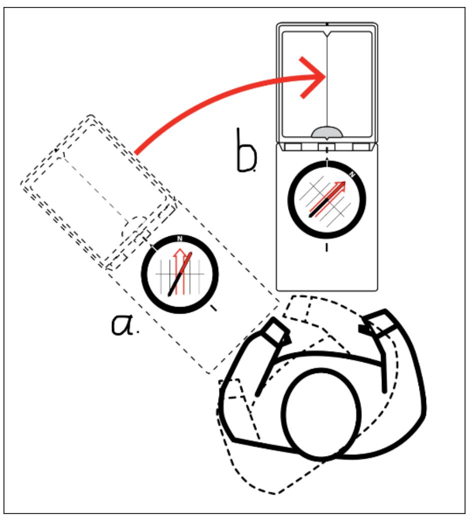


Fig. 3-18. *Following a bearing in the field with a baseplate compass, with a previously measured bearing set at the index line: a, the compass needle is not aligned (Red is not in the shed); b, rotate your body and compass together as a unit until the orienting arrow is aligned with the compass needle. The direction of travel arrow now points in the direction of the bearing.*

[Artist note: 1) The compass needle should not move; they should be precisely parallel; 2) Draw the compass without a mirror; 3) Draw a bit of the lanyard as a subtle reminder.] *, COMMENT. . The bearing has remained unchanged,* TRAVIS: I think it would make sense for this to be steps a-b-c where step a is rotating the housing to "set" the desired bearing. TRAVIS: As you turn, you are changing the bearing (well, from a certain point of view). This might be clearer if you said: "without adjusting the housing"? I don't know because about you say you turn the baseplate, housing and yourself. I would argue you are turning the baseplate and your body, but not the housing. You DO rotate the housing initially to "set" the bearing you want to align to. TRAVIS: I think I'm getting overloaded meanings of bearing confused in my head as I read this. I think of it as "the direction I am point is my heading, and I want to align my heading with the bearing I set on the compass." Do you use a term for "the direction you are facing" in the book? Maybe "heading" is something I kept from the Navy (like my haircut...)

STRAIGHT-LINE COMPASS TRAVEL AND DRIFT

Regardless of skill level, landscape, and measurement error conspire against the navigator attempting to travel in a straight line. It is a critical concept that once you have drifted laterally left or right, *the bearing on your compass will no longer point you toward your objective.*

Example of lateral drift. Imagine traveling off-trail through a wooded area following a compass bearing of 338° back to your camp by a river. Even when the original bearing to camp is accurate, all travelers will have a lateral drift to the right or left. See Figure 3-19.

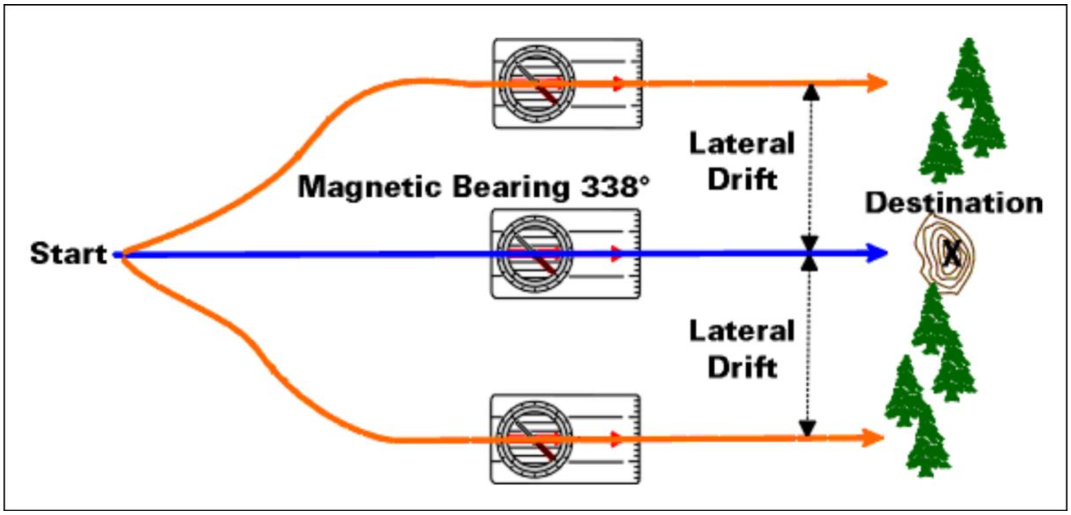


Fig. 3-19. *Lateral drift while following a bearing.*

{artist note, change "magnetic bearing" to "compass bearing." Make Fig. 3-19 similar to Fig. 3-21, using a river as a backstop. Use a bearing of 90°; differentiate between the meandering that has happened (dashed line) with the new 90-degree bearing; don't have the lines obscure the compasses.}

ACCOMMODATING DRIFT WHEN USING A COMPASS

How do skilled wilderness navigators use a compass and a bearing to travel to their destination despite the inevitability of drift? Here are three navigation techniques to accommodate drift:

Method 1: measure a new GPS bearing. Following a GPS bearing with a compass and the ability to update it as needed is a significant advancement in wilderness navigation. This technique, known as "live navigation," leverages real-time data to guide travelers to their destinations. We are accustomed to this concept through applications like Google Maps and Waze, which provide real-time updates to help us avoid traffic or road closures. The navigator is freed from

TAKING A BACK BEARING

Once a bearing has been measured, a back bearing, which is 180° offset, is measured as follows:

- Use the magnetic needle's black (south) end as you would typically use the red (north) end. "Put Black in the Shack" is a mnemonic that may help, or
- Add or subtract 180° from the bearing as needed to keep the bearing below 360°.

attempting straight-line travel when using live navigation. As long as progress is made toward the objective, the navigator knows they can regularly re-measure a new GPS bearing toward the objective. It is important to remember that a GPS bearing provides both the bearing and the distance to the waypoint representing the objective. Progress is being made as long as the distance decreases. The objective can be reached through this iterative process. This book's most important off-trail technique uses updatable live navigation bearings with a compass to guide us to our next waypoint.

I'M NOT DEAD YET

"Dead reckoning" is a backup navigational technique that follows a bearing in a straight line from one known location toward another without reference to visible landmarks, celestial bodies, or GPS. This originally nautical method is often challenging for land navigation where terrain can make straight-line travel difficult or dangerous.

In this context, "reckoning" means calculated. A ship would reckon or calculate its position using only its bearing, speed, and elapsed time. The meaning of "dead" is uncertain but may refer to traveling "dead ahead."

With wilderness navigation, sometimes things go awry: GPS dies, visibility is low, or lines of position are scarce. In those circumstances, we may only have a bearing to the desired location or the next LOP, so dead reckoning becomes your fallback.

Method 2: use a map and compass together. When GPS is unavailable for method 1, you can use the techniques of Chapter 2 that focus on navigation with only a map, primarily through physical lines of position. If you can identify on your map and in the landscape a trail, stream, ridge, or gully going in your direction, you have a LOP to function as a handrail to guide you forward. A compass can help keep you on the intended LOP. Set the compass to the bearing of LOP, as measured on the map. Then, check your direction of travel along the LOP with the compass. If there is a discrepancy, stop and assess. Similarly, you can align the map with the landscape to see if the LOP you are traveling is parallel to the LOP on the aligned map. This technique is detailed under "Orienting the Map to North" below.

Method 3: dead reckoning. Dead reckoning is a fallback navigation technique used only when methods 1 and 2 described above have failed. The technique is tedious and prone to cumulative errors from drift ~~that accumulate over time~~. Nevertheless, the accomplished navigator prepares for the stormy night when their electronics fail and a featureless snowfield or desert must be traversed.

Example. Consider a situation where a navigator, following a previously measured bearing toward a mountain pass, encounters unfavorable weather conditions obscuring the intended route. In such cases, utilizing a compass for dead reckoning can aid in maintaining the correct bearing. While compass travel drift is inevitable, it can be minimized using good dead reckoning technique.

Dead reckoning technique involves traveling in a straight line until a backstop is reached. Theoretically, elapsed time and speed can be used to calculate the navigator's new position, but computing speed while attempting to travel in a straight line over rough ground is impractical.

Using the military technique of “pace count” (step counting) is more practical. This specialty technique is covered in Section III.

When dead reckoning is needed, GPS failure has thwarted the use of Method 1, and poor visibility has made the high-visibility map and compass techniques of Method 2 unavailable. The first step of dead reckoning is measuring a map bearing toward your objective. The second step is determining a backstop, such as a trail, elevation, or clearing, that marks your objective or the location of a necessary turn.

Without GPS or the availability of distant landmarks, straight-line travel is accomplished by finding intermediate objects along your measured bearing. Using the techniques described above for using a bearing in the field with a compass, find a memorable object that lies along the path of the bearing that you can keep in sight as you travel toward it. The object can be an unusual tree, a memorable rock, or a distinct change in the landscape. The distance can be as far as is practical to minimize the number of legs or repetitions.-When no memorable intermediate object is available, use a teammate, a technique called “leapfrogging.” While using a teammate is slower since you have to wait for them to get in position, your teammate, particularly one with a headlamp[13], is the most accurate “intermediate object” you can have. Your partner can move precisely onto the desired bearing by responding to your prearranged hand-waving directions and taking a back bearing (see inset) on you to help determine where they should stand. And while unusual trees and memorable rocks can lose their distinction in a forest or rockpile, your well-lit teammate will not.

Now, travel *to the object* or teammate and repeat the process by finding another object or placing your teammate or yourself again along the same bearing. Swinging leads gives us the term “leapfrogging” but “caterpillaring,” sending the same teammate forward is also appropriate. If the object is unreachable, travel *past the object,* take a back bearing on the previous object, and adjust your position (but not the bearing!) until you are standing along the back bearing. You are now standing along the path of the original bearing. Repeat the above process by finding another object along the original bearing. Continue until additional information becomes available or you reach your intended backstop, such as a road, river, or elevation measured on an altimeter.

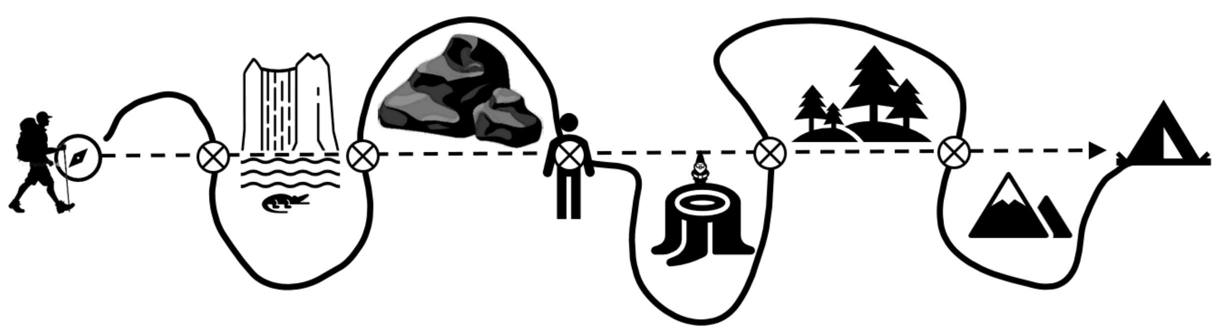


Fig. 3-20. Dead reckoning using intermediate objects or teammate: Dashed arrow, bearing measured for travel; solid line, actual traveled route; circle with X, intermediate objects; Person with X, teammate used for leapfrogging.

[13] A teammate with a headlamp can significantly increase both the distance of each leg and increase accuracy.

Navigating Nature's Obstacles. Using leapfrogging and intermediate objects works even when straight-line travel is blocked due to nature's impediments. See Figure 3-20. The blockages might include dense vegetation, hilly terrain, fog, heavy rain, snow, and featureless terrains such as deserts, glaciers, plains, or intricate canyons. Even though the navigator cannot walk directly to the object, once identified, the navigator can travel to the object by the easiest route. Once there, the navigator can find objects past the subsequent blockages that lie on the exact intended bearing. This process can continue until the objective is reached, although the farther you go, the greater the drift. Often, the navigator cannot conveniently reach the intermediate object at all. In this case, the navigator should walk past the object and take a back bearing, as described above, to stay on the original bearing.

Aiming off. Aiming off is a valuable technique during dead reckoning when circumstances permit. In our example, "Lateral drift while following a bearing" (Figure 3-19), our previous camp is situated alongside a river, which can serve as a reliable backstop. If we aim directly at our camp, we are unlikely to hit it precisely, so we would be uncertain whether to turn upstream or downstream to locate our camp. To address this, we use the straightforward technique known as "aiming off." Instead of aiming directly at our camp, we intentionally offset our bearing by aiming upstream or downstream. Doing so lets us know which way to turn toward our camp. We will not know the distance to camp, but we will know what direction to follow the river. Please refer to Figure 3-21 for visualization.

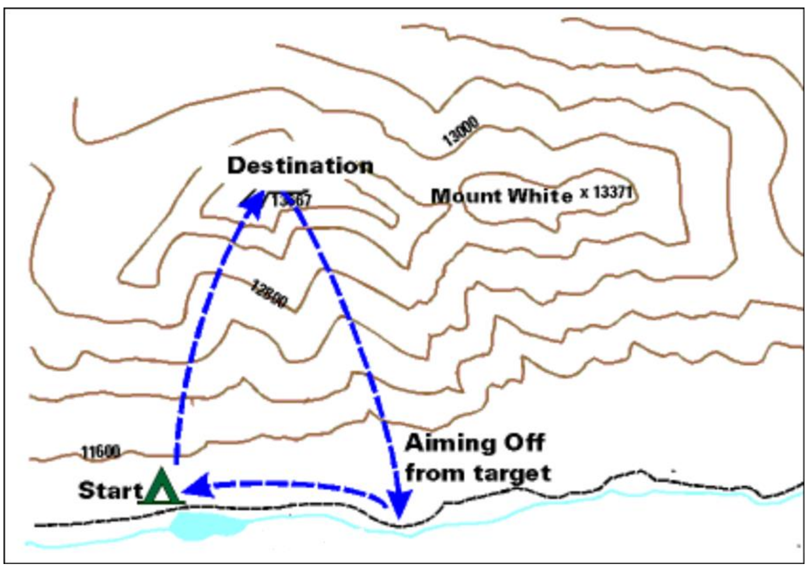


Fig. 3-21. *Aiming off using a backstop.*

{Note to the artist: Replace the word Start with Camp. Replace Destination with Start. Show one straight line (not curved) as "bearing directly to camp" and pointed toward camp, and the other (again, straight, not curved) as "bearing aiming off" or "bearing aiming off of camp."}

ORIENTING THE MAP TO NORTH

Having your map oriented to the landscape is a simple but powerful navigational technique that is often overlooked.

Orienting the map. In Chapter 2, under “Where are we?” we discussed aligning the map with north to verify whether the landscape corresponds with the map. This is often a simple matter of turning the map until prominent features observed in the landscape align with the map. When the landscape makes this difficult, align the map by using your compass as follows:

Step 1: Set the bearing at the index line to north (000° or 360°), the typical bearing for any map’s edges, and always the bearing for longitude lines. UTM lines can vary from north by a few degrees.

Step 2: Align either of the baseplate compass’ long edges with any north-south line on the map. Now, treating the compass and map as a single unit, turn them until the magnetic needle is aligned with the orienting arrow. When Red is in the shed, the map is aligned with the landscape while you are still facing your direction of travel.

Why bother? Matching features on the map to the features you see in the real world can often help you to determine landmarks, find your approximate location, and “keep your bearings” in an unknown location. If you are traveling along a trail, ridge, valley, or any line of position, comparing the orientation of the LOP on the map with the LOP under your feet can tell you whether you have veered off onto a different LOP. If the bearing of the LOP on the map and the LOP under your feet are different, you are definitely on the wrong LOP. If they are the same, you are on the right one (or perhaps one that is parallel).

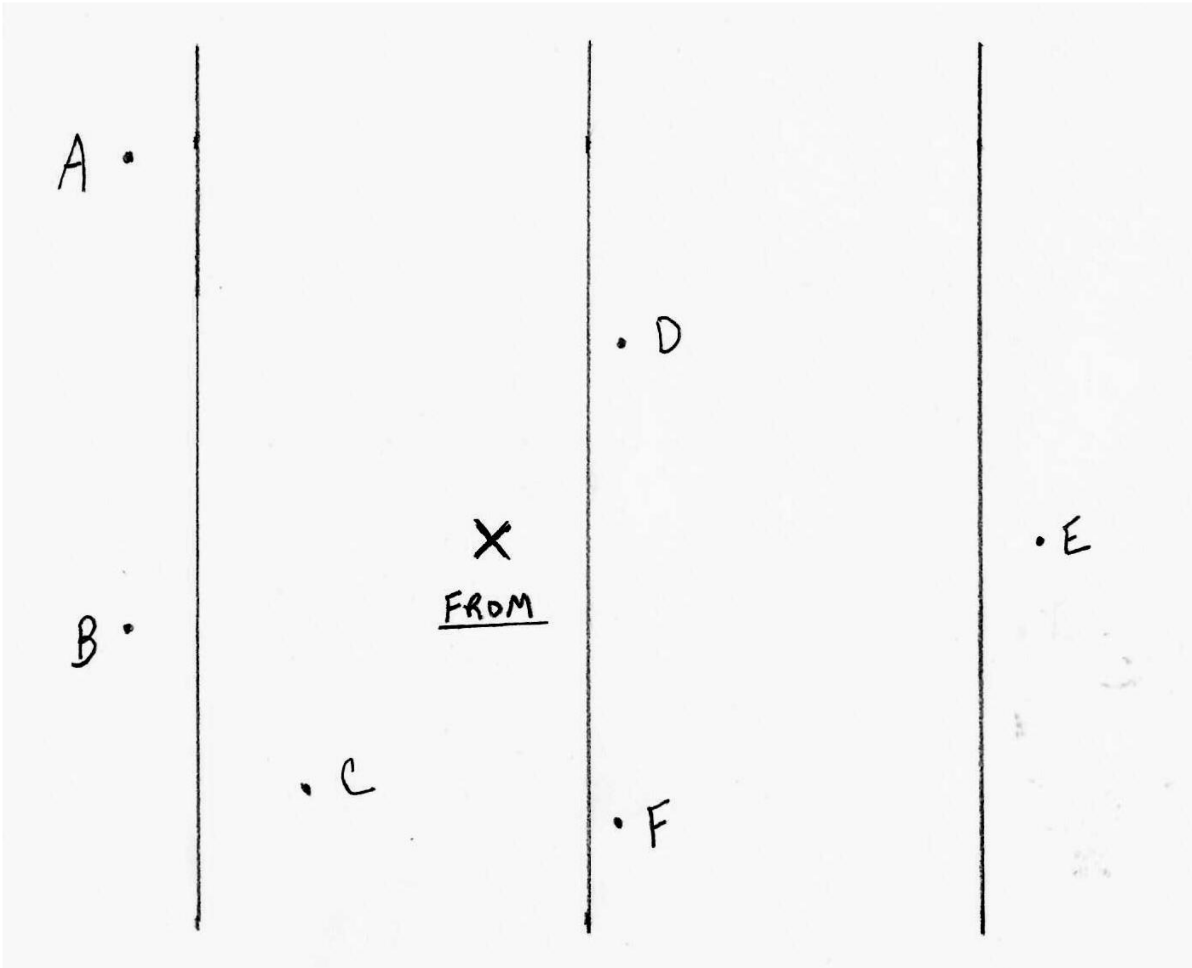
Imagine you are facing north with the map in front of you. If you spot a distinct mountain to the west on the map, it will be to your left in reality. Landscape features north of you on the map will be ahead of you, those to the east will be to your right, and those to the south will be behind you. But it is usually most helpful to face your direction of travel while holding the map (placing it on the ground is often helpful) oriented to north. For example, if you are traveling east, north and the north end of the map will be to your left. If you are traveling west, north and the north end of the map will be to your right. If you are traveling south, north will be behind you and the map will be upside-down! Even in this last case, where the map labels are hard to read, matching the landscape to the map will be more intuitive. Objects you are facing will be ahead of you on the map (south), those to your left will be to the left (east) on the map, and so on. Engineers, mechanics, and architects are used to looking at blueprints and rotating them in their minds, but for us mortals, orienting the map is a simpler alternative.

Example 1, the right trail? Imagine one foggy day you are traveling due north on a trail. Accidentally, you took a left turn onto a trail that heads northwest. To confirm whether you are on the correct trail, you take out your map, set the bearing to north, and orient the map. You find that the line of the northbound trail on the oriented map and the trail under your feet are not aligned. You are not on the right trail. One day, while hiking in these exact circumstances, I informed my buddy that we were on the wrong trail. The belief that we were on the right trail was so powerful that he took the map, rotated it until it matched the trail under our feet (but no longer oriented north), and declared we were on the right trail. But no, the map was correct. We turned around.

Example 2, the right intersection? Imagine you are hiking due west on a trail and watching for an intersection with another trail that turns to the right. It is the only other trail marked on the map for a considerable distance. You spot such a trail but pull out your map to quickly verify by orienting the map to north. You set the compass to 000°, align it with the left edge of the map, and then turn your map and compass until the magnetic needle is aligned with the adjustable orienting arrow. While you are still facing west, north on the map and in the landscape are to your right. First, you note that the trail on the map and the one under your feet are parallel. You have verified you are on the correct trail, but is this the correct intersection? You can easily see that the trail at this intersection is not parallel with the one on the map. It is not the correct intersection and must be an unmarked trail, a common occurrence. Alternatively, you could have measured the bearing of the desired trail on the map, and then, without further need to set the bearing on the compass, you could see if it aligns with the trail. It would not.

Example 3, the curving trail. Imagine you are hiking a winding trail and then spot the anticipated intersection that turns to the right, as on the map, at a 45° angle. Is it the correct trail? By aligning the map to north, you can quickly see if the bearing of this new trail is parallel with the one on the map. If they are not parallel, it is not the correct trail. If they are parallel, it is the correct trail or another trail that happens to be parallel with the one you seek.

Map Bearing exercise. Imagine you are on the map below (Figure 3-22) at X. First, using the compass rose in Figure 3-23, quickly estimate the bearing from X, your location, to each letter. For beginners, guess from only the eight principal directions (north, northeast, east, etc.) and use its bearing (000°, 45°, 90°, etc.). A significant error of plus or minus 30° is acceptable since we are primarily trying to avoid the classic "180° error." Next, using your compass as a protractor, measure the bearing from the center of the X to the dot next to each letter. Remember to put the lanyard end of the compass at your location (the X) and to ignore the magnetic needle and the orienting arrow:



	Rough Estimate	Measurement		Rough Estimate	Measurement
X to A			**X to D**		
X to B			**X to E**		
X to C			**X to F**		

Fig. 3-22. *Map bearing exercise. {ARTIST NOTE: Substitute an actual map for the diagram above using actual locations on the map.* ***ADD R CODE SO THE QUIZ CAN BE DOWNLOADED.****}*

Answers: X to A is 316°, B is 256°, C is 216°, D is 34°, E is 90°, F is 156°.

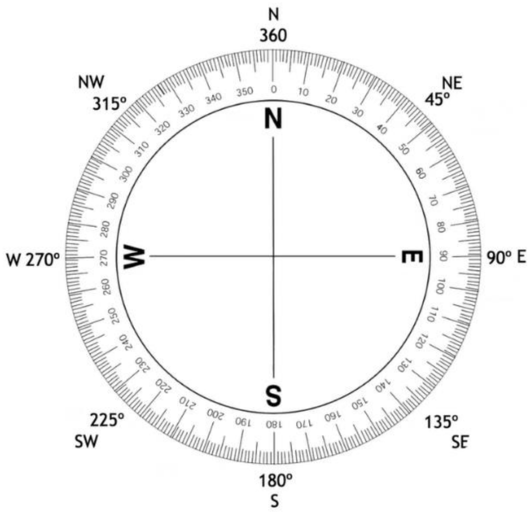


Fig. 3-23. *8-point compass rose with bearings.*

<<Situational Awareness
SECTION Goes HERE.
Coordinate with Pg. 42 and F/N 5.>>

Chapter 3 Conclusion

Enhancing our navigation toolkit, Chapter 3 introduced the compass, a tool that complements map and GPS navigation. We explored the compass's ongoing relevance, formats, features, and techniques for measuring and using bearings. Declination and how to mitigate its effects were also examined. We looked at how to measure and then use GPS bearings, map bearings, and compass bearings. To counter the effects of drift, we delved into three techniques. Additionally, the process of orienting the map to the north was explained.

The compass will become an indispensable tool as we continue exploring wilderness navigation. Its ability to provide accurate bearings and enhance situational awareness makes it a valuable asset, helping you to navigate confidently and safely in diverse wilderness environments.

Chapter 4 will introduce the altimeter, a tool that measures our second instrument LOP, elevation, which is crucial in hilly or mountainous conditions.

INTRODUCTION TO SECTION II: LOW-VISIBILITY NAVIGATION BY INSTRUMENT

It's always further than it looks.
It's always taller than it looks.
And it's always harder than it looks.
— Reinhold Messner

I learned to play tennis in the 1970s, and a few years ago, I picked up a racket again to play a friend of mine. I dusted off my long swooping strokes from the wooden racket era and held my own, but my friend shook his head, "Steve, we don't play tennis that way anymore." And so it is with modern wilderness navigation. A map and compass will still guide you on a sunny day, and you can still measure a bearing from a map and follow it in a straight line, *but we now have additional tools in the toolbox.*

On a well-trodden trail, in high-visibility conditions, a compass still yields assurance that the trail under your boots is the right one. But map and compass alone can be overpowered by conditions such as those of the rainy northwest of the United States, a dominion of dense forest, fog, and snow cover. Here, help arrives from our low-visibility instruments: the altimeter, digital maps, and GPS.

Low-visibility tools are not mere supplements to our physical map and compass; they fundamentally change how we use our maps and our compass. As large-headed graphite rackets changed the way we stroke the tennis ball, electronic tools have changed how we measure bearings, follow routes, and use maps.

Section II begins with Chapter 4, which introduces our third tool, the altimeter. This device tells us which contour line we are standing on, an immensely helpful clue to our location. In Chapter 5, we will further explore digital maps and learn about GPS apps: how they work, how we prepare them for the backcountry, and finally, the three ways we use them to navigate.

Chapter 4

Third Tool - Altimeter

Introduction

Altimeters, digital maps, and GPS are indispensable for safe navigation in challenging conditions and prove beneficial on clear, sunny days. Chapter 2 explored how to determine location by looking at our map and in our surroundings for intersecting natural lines of position. But if the sky is dark or the woods are thick, there is little to observe, so these methods can fail us. Here, the altimeter emerges as a crucial addition to our navigation toolkit.

The altimeter stands out for its simplicity and value among the five essential navigation tools, especially in hilly or mountainous terrain. Two or more lines of position will determine your location, and altimeters easily give us one even when visibility is low—the approximate topographical line we are standing on. Only one other scrap of information, such as a trail, a ridge, or a river, will give us a second LOP to help us determine our position. Imagine the usefulness of an altimeter when climbing the Pyramid Peak Trail (see Figure 4-1):

- **LOP-1:** Your altimeter says you are standing on a 6,600 ft contour line.
- **LOP-2:** You believe you are on the trail that ascends the southeast ridge of Pyramid Peak, giving you a second LOP. If there is any doubt, the map tells you that the trail proceeds uphill a bit north of northwest. This can be confirmed using a compass.
- **Position:** The two LOPs intersect only at one point, allowing us to determine our position is the A on the map below. This is easy, and your position can be determined regardless of visibility.

KEY TOPICS
ELEVATION: SECOND INSTRUMENT LOP
FORM FACTORS
WHERE AM I?
MORE FUN

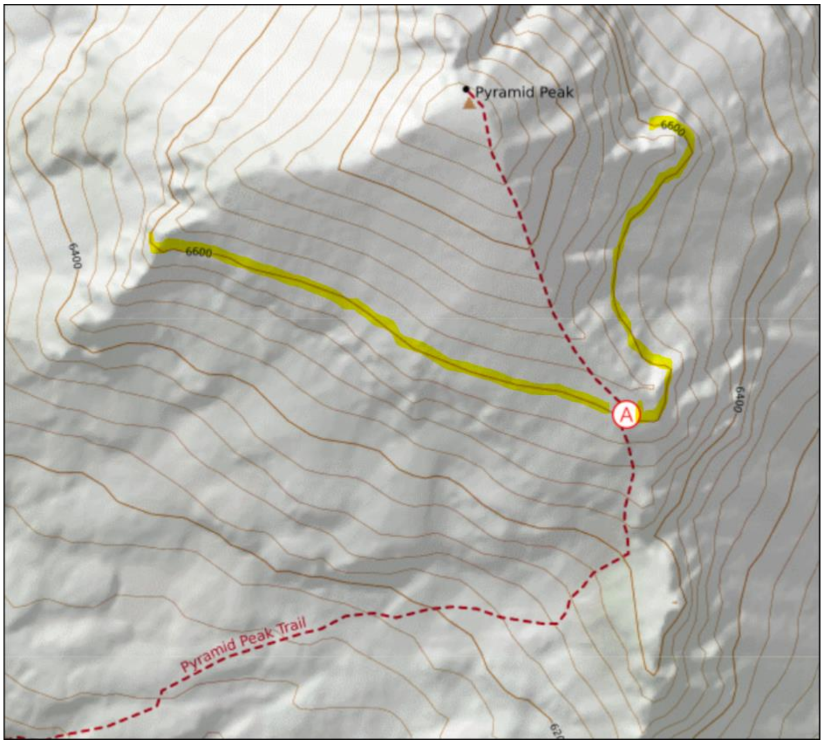


Fig. 4-1. Example of determining location with an altimeter.

Altimeter Form Factors

Formerly, altimeters were expensive stand-alone devices but now are typically part of a stand-alone phone app, multi-function GPS device, or smartwatch, and they compute elevation using one or more of three methods. See Table 4-1 for a comparison of altimeter form factors and Figure 4-2 for examples:

Phone app. Phones virtually all have GPS chips, and most have pressure sensors. Phone altimeter apps are free or low-cost and calculate elevation using any or all of the methods explained below under "How High Are We?". However, many apps are not clear about how they compute elevation. An app's method of determining elevation is important so you know how the weather, poor GPS reception, or internet availability might affect the calculation. Phone apps have the most functionality but are often safely stowed away and frequently off, making them inconvenient for a quick elevation check.

Dedicated GPS Device. These rugged devices have little flexibility about how they compute elevation and tend to be opaque about their methodology. Some devices exclusively use GPS data for elevation. They use a pressure sensor and then GPS for calibration. Using a proprietary methodology, Garmin dedicated GPS devices combine barometric data with GPS self-calibration.

ALL-WEATHER INSTRUMENTS

While the clever tools of low-visibility navigation—altimeter, digital map, and GPS—are critical for safe exploration under adverse conditions, they are also appropriate on bluebird days.

Wrist altimeters. Sports watches and smartwatches have a ready answer to the persistent question, "How far is the top?"

- **Sports watch.** Inexpensive sports watches, often called "ABC" watches for their altimeter-barometer-compass functionalities, are available for as low as $50. Lacking GPS capabilities, they rely on a pressure sensor that can be calibrated either as an altimeter for hiking or, theoretically, as a barometer for weather forecasting. These watches typically have a battery life measured in years.
- **Smartwatch.** These sophisticated wrist computers cater to the growing fitness device market. Brimming with an array of sensors, some models include digital maps, waypoint, route, and track capabilities. Similar to dedicated GPS devices, the altimeter in smartwatches utilizes both pressure sensors and GPS to calculate elevation using a proprietary methodology. Non-navigation sensors such as the pulse oximeter can be deactivated to conserve battery life during extended trips. The entire watch can be powered off once camp is established. Smartwatches, however, often have a relatively short battery life (approximately 5 to 10 days) and require proprietary charge cords, necessitating the correct cord for recharging during a trip.

TABLE 4-1. ALTIMETER FORM FACTORS.

Form Factors	Methods	Comments
Sports watch Stand-alone battery-free device (rare)	Barometric altimeter	Must be regularly recalibrated against known elevations or GPS. Inexpensive. Long battery life or no battery.
Phone app (e.g., Gaia GPS, built-in Apple compass app)	GPS altimeter	Apps may or may not adjust for the difference between the ellipsoid and actual sea level. The choices are numerous. Dependent on having a working phone. Inexpensive.
Phone app (e.g., CalTopo)	Location-based altimeter	Dependent on internet access unless elevation data can be downloaded in advance or occasionally embedded into maps. Inexpensive.
Phone multi-function app (e.g., Accurate Altimeter for Android from ARLabs)	Multiple methods	Some apps will give a separate elevation for each method used. Inexpensive.
Smartwatch	Multiple methods	Convenient. Fun. Expensive.

Dedicated GPS device	Multiple methods	Rugged. Complex. Expensive.

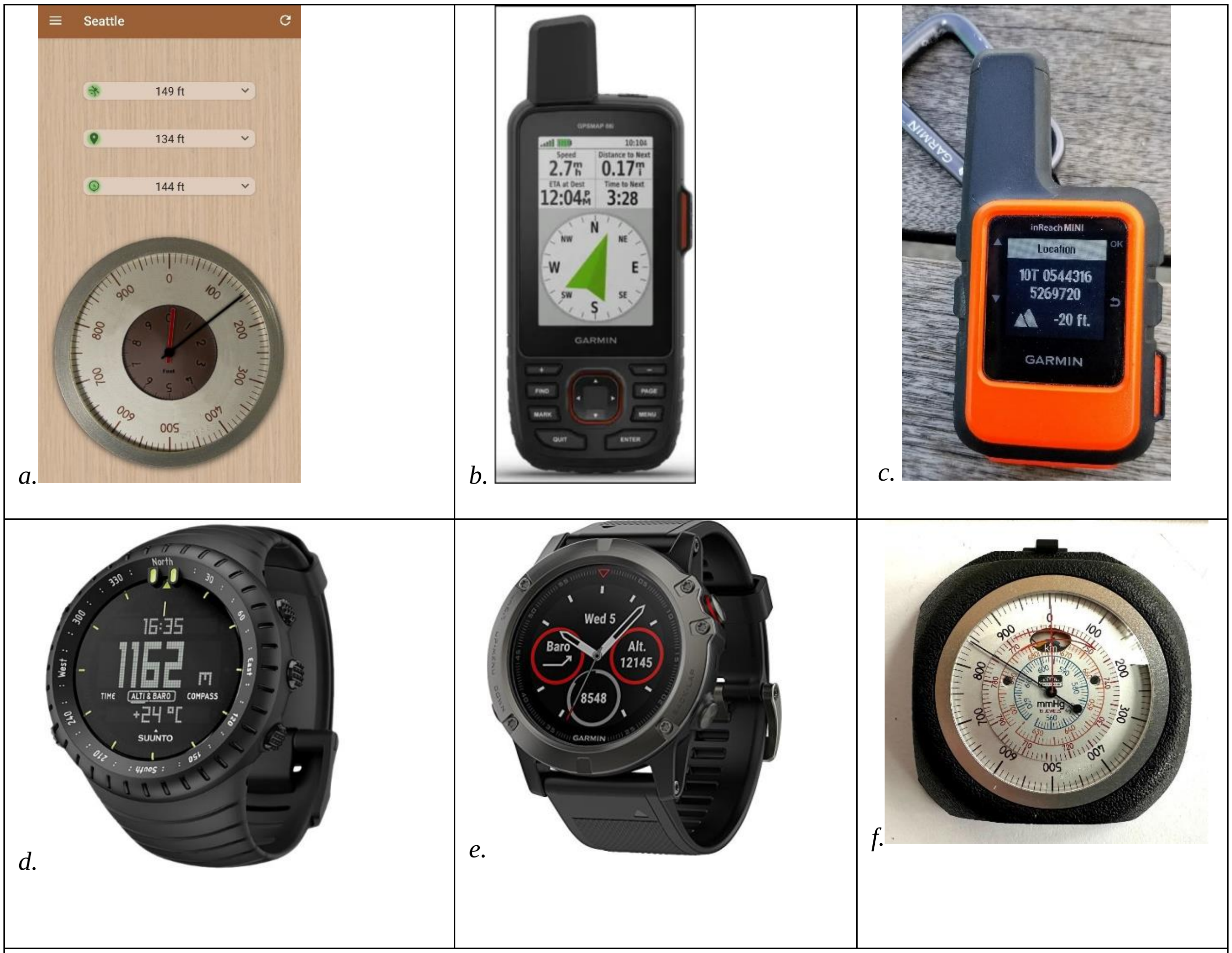


Fig. 4-2. Example altimeters: a, multi-method phone app; b, Dedicated GPS device with satellite communication capability; c, Garmin inReach satellite communication device; d, ABC sports watch; e, GPS watch; f, mechanical barometric altimeter shown for historical comparison.

How High Are We?

There are three ways that an altimeter can determine your elevation. Some devices will use multiple methods and, of course, calculate multiple answers:

- **Barometric altimeter.** Before GPS, all altimeters determined elevation by measuring the subtle decline in air pressure as elevation increases. Barometric altimeters measure air pressure like a barometer but are calibrated in feet or meters rather than inches of mercury or millibars. Barometric altimeters are significantly affected by changes in atmospheric pressure caused by weather and by temperature or humidity that vary significantly from the standard. For this reason, barometric altimeters must be regularly recalibrated at known elevations or against GPS. While still online, some altimeter apps can be automatically calibrated against the known elevation and current air pressure at nearby airports. Early altimeters were intricate mechanical devices driven purely by changes in air pressure. While such mechanical battery-free models can still be found, all modern barometric altimeters measure the change in electrical resistance in a pressure transducer caused by elevation change.

- **GPS altimeter.** A GPS device measures not only coordinates such as latitude and longitude but elevation in the "Z dimension." This elevation measurement is inherently less accurate than the X-Y latitude and longitude measurement due to the geometry of GPS satellites.
- **Sea level vs. ellipsoid.** Topographic maps use actual sea level for elevation, but GPS altimeters use their X-Y-Z location to calculate their height above a simplified mathematical approximation of the earth's sea level called the ellipsoid. Better devices or apps then adjust for the "ellipsoid height," the difference between the ellipsoid and actual sea level. Some do not, which can result in an error of up to 330 ft (100 m) in either direction, depending on where you are on the earth. These non-adjusting devices and apps are a primary cause of the GPS altimeter's undeserved reputation for poor accuracy. Devices and apps are rarely clear about how they compute elevation. Luckily, the difference between sea level and the ellipsoid is nearly constant over large areas. You may see a systemic error if you check your GPS altimeter against a known elevation. Usually, this error is irritating, especially when you are at the ocean, and it shows you below sea level, but it is too small to have a material effect on navigation.

Elevation-smart Maps

CalTopo embeds elevation data into its digital maps, providing the simplest and most accurate method for determining elevations.

- **Location-based GPS altimeter.** A GPS device can also ignore the Z dimension and use only the X-Y latitude and longitude measurements to find your elevation on a global digital elevation model. The device inquires, "I'm at this location, so what is my elevation?" Most of these devices need an internet connection to make the inquiry. Some allow you to download a subset of the digital elevation model or capture this data embedded in downloaded digital maps.
- **Multiple methods.** Some devices and apps will use multiple methods to determine elevation. At a basic level, some apps will use the phone's GPS chip and the pressure-based chip if both are present and display both elevations separately. GPS devices and smartwatches made by Garmin measure elevation using a pressure sensor but then continually but slowly recalibrate using GPS.

Elevation or altitude?

Altimeters are used to measure altitude and elevation, two terms used to describe the height of an object above a reference point. However, there is a subtle difference between the two terms.

Elevation is the vertical height of a point on Earth's surface above mean sea level. It is used to describe the topography of a particular location. For example, the elevation of Mount Everest is 29,031 feet (8,848 meters). The term elevation will be used exclusively throughout the other parts of this book.

Altitude is a more general term used to describe the height of an object above a reference point, which varies depending on the context. For example, the altitude of an aircraft is measured above ground level for takeoff and landing but above mean sea level during flight.

Where am I?

There are unlimited ways that you can combine the LOPs that we learned about in Section 1 with our new instrument LOP, elevation. There are two cautions in order. First, you need to know which mountain you are standing on. An altimeter reading of 5,000 ft means you are standing on the 5,000 ft contour that snakes its way around the mountain under your feet, but there may be several nearby peaks with 5,000 ft contours. *You need to know which peak you are standing on.* Second, two straight LOPs can only cross in one place (your location), but the more serpentine the LOPs, the more places they can cross, and your location can be at any of the intersections. And yet, knowing you are at one of a small number of locations rather than anywhere on the map are precious clues. From there, it is typically easy to narrow down your actual location from a handful of choices.

Here are some examples of using the altimeter with other physical or instrument lines of position. A digital map will simply indicate your position. These examples assume you do not have a digital map available. This circumstance can occur for many reasons, including a change in plans, failure to download the proper maps for whatever reason, or equipment failure. In each example, the LOPs are highlighted in **bold text:**

- You are hiking up a hill on a trail. The map says there is a junction at 4,000 ft. and one at 5,000 ft. You come across a trail junction and check the elevation on your altimeter, which reads 4,000 ft. You are at the lower junction since your location is at the intersection of the **trail** and the **4,000 ft contour line**.
- On a foggy day, you are hiking off-trail up a ridge to a camp at 6,000 ft and want to check your progress. Your altimeter indicates your elevation is 4,400 ft. Your location is where the **ridge** intersects the **4,400 ft contour line**. You have 1600 ft more to climb.
- You are hiking on one side of a long valley. On the other side of the valley, you notice a transit, two peaks that align with your position, and you can confidently identify them on your map. Your altimeter indicates your elevation is 3600 ft. Your location is where the **transit** drawn from the two peaks to your position intersects the **3,600 ft contour line**.
- You are hiking on one side of a long valley. On the other side of the valley, you notice a peak you can confidently identify on your map. Measured from your position, your compass indicates this peak lies on a bearing of 280 degrees from true north. Your

altimeter indicates your elevation is 3,000 ft. Your location is where a **bearing line of 280 degrees** that passes through the peak intersects the **3,000 ft contour line**. Note that a bearing could intersect with a wavy contour line in multiple locations. When this occurs, you will have narrowed your position down from anywhere on the map to a handful of locations. You should be able to determine your location with other bits of data.

- You are hiking toward a river with a beautiful waterfall at 2,400 ft. You do not want to waste time hitting the river too far above or below the waterfall. As you approach the **river**, adjust your course up or down to be at the **2,400 ft contour line** when you hit the river. You take a beautiful picture.

More Fun with Altimeters

Rate of ascent. Getting to our objective in the wilderness often involves significant ascent or descent. Keeping track of this rate of ascent or descent can help determine how long it will take to arrive at our objective or whether the current plan is still reasonable. For example, if the altimeter indicates the party is at 5,000 ft and the objective is at 8,200 ft, there is 3,200 ft to climb. If the rate of ascent has been 800 ft (240 m) per hour, the party can anticipate it will take four hours to reach the objective, assuming they maintain their current rate of ascent.

Direction-of-slope method. With the direction-of-slope method, you can determine your location (or a small number of possible locations) using only a topographic map, an altimeter, and a compass, even in zero visibility. Imagine you are on the side of a somewhat uniform peak, and your altimeter tells you your elevation is 4000 ft. You know your feet are planted on the 4000 ft contour line encircling the mountain.

Knowing your elevation is a huge help, but with no other LOP—an identifiable trail, ridge, or stream, for example—how do you determine your location on that wavy circle? Imagine you were to roll a bowling ball straight down the fall line. The bowling ball would travel perpendicular (at a 90-degree right angle) to the contour line. As covered in Chapter 3, take a bearing on your imaginary bowling lane down the hill. Assume that the bearing is precisely 180 degrees. Looking at the map, where could a line perpendicular to the 4,000 ft contour line aim at 180 degrees? You may find only one location, but mountains are rarely regular in contour, so you may have several answers. These multiple options are invaluable clues; with other bits of data, you should be able to determine your location.

Example in the wild. It is surprisingly easy to get turned around on a summit. As you ascend, the number of routes going up diminishes, while on the descent, the number of routes increases exponentially. In a whiteout atop Mt. Rainier, some friends of mine got turned around within the summit crater during a successful climb and descended using an incorrect route. Figure 4-3 displays the three primary climbing routes on the mountain. Envision how readily they could have recognized their mistake by confirming their elevation with an altimeter and then taking a rough bearing on the fall line as they began their descent at the crater's rim.

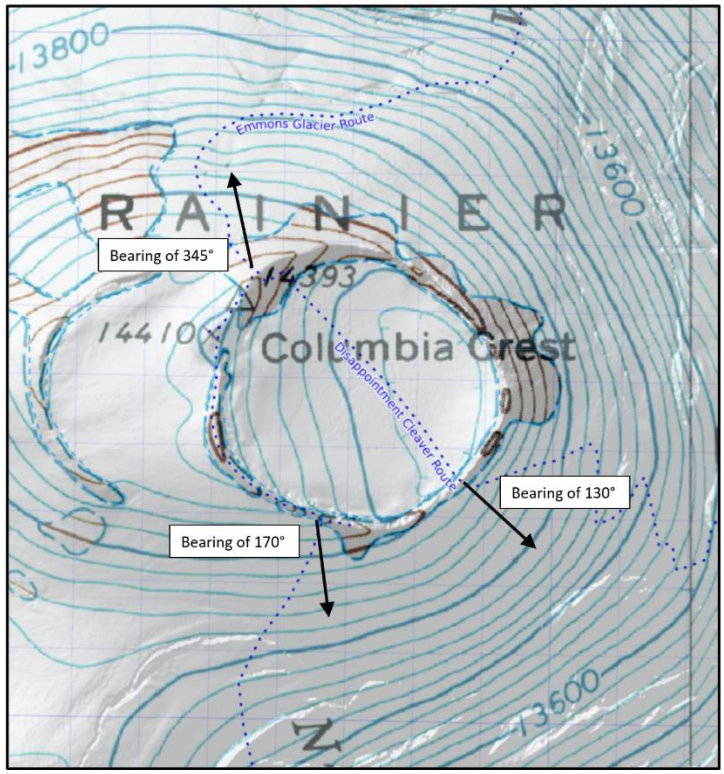


Fig. 4-3. Most common climbing routes on Mt. Rainier, Washington State, and a bearing on the fall line at the crater rim for each.

Chapter 4 Conclusion

After the map (Chapter 1) and compass(Chapter 3) , Chapter 4 introduced the altimeter, the third tool for wilderness navigation. The altimeter measures our second instrument LOP, elevation, which is crucial in hilly or mountainous conditions. The chapter looked at the available form factors for altimeters and the three methods they use for measurement, as well as elevation-smart maps. The chapter looked at ways an altimeter can assist with navigation.

Chapter 5 will reveal the magic of our capstone tool, GPS.

Chapter 5

GPS Magic

> "Any sufficiently advanced technology
> is indistinguishable from magic."
> – Arthur C. Clarke's Third Law

GPS is an amazing technology that could fill pages with diagrams of satellites whirling around the globe, tales of atomic clocks, and the effects of Einstein's theories of relativity. Although fascinating, superficial knowledge of how these systems work is sufficient.

Chapter 5, GPS Magic, will provide the background information needed before navigating with GPS. First, we demonstrate the basic mechanics of GPS. Then, it will reveal the formidable power of GPS apps with their constant companions, digital maps, and overlays. It will then teach the language of position, explaining both the latitude and longitude system and the UTM system, the two primary ways of describing a position on the Earth. It will teach you to "speak" this language with a GPS device, a physical map, or aloud, perhaps in a rescue situation. It will then demonstrate how to translate coordinates between formats easily. We will cover the lowly grid line, the critical link between GPS, our most potent low-visibility instrument, and the physical map, the first tool of high-visibility navigation. This chapter will conclude by explaining how to use a GPS device alone, with a compass, or with a map using three techniques: On-trail GPS, Off-trail GPS, and Coordinate-only (basic) GPS.

GPS Mechanics

HOW DOES GPS WORK?

"GPS," the acronym for Global Positioning System, originally meant the constellation of navigation satellites operated by the United States Air Force that became fully operational in 1993. After the US system deployment, three additional Global Navigation Satellite Systems (GNSS) have become available for civilian use. Russia has developed GLONASS ("glo-nass"), China has developed BeiDou ("bay-dough"),

KEY TOPICS
GPS MECHANICS
APPS AND MAPS
LANGUAGE OF COORDINATES
MEASURING UTM
TRANSLATING COORDINATES
GPS NAVIGATION

and the European Union has developed Galileo. In addition, Japan (QZSS) and India (IRNSS) have regional systems in operation. This book uses the term GPS to mean the world's collection of GNSS and the related devices we hold to navigate wild spaces.

GPS devices are only receivers; they do not transmit any signals. These receivers are tuned to listen to the radio frequencies of the various GPS systems. The GPS satellites, which circle the earth twice daily in medium earth orbit[14] at about 12,000 to 14,000 mi (about 19,000 to 23,000 km), broadcast a continuous signal. The signal contains the satellite's identity, coordinates, the exact time it was sent (based on the satellite's atomic clock), and " almanac data" about the entire satellite constellation. Using the satellite's location and the time delay between when the signal was transmitted by the satellite and when it was received, the GPS device uses the speed of light to compute the distance to the satellite. GPS devices repeat this distance computation to satellites of known position many times to crunch the math to determine its location.

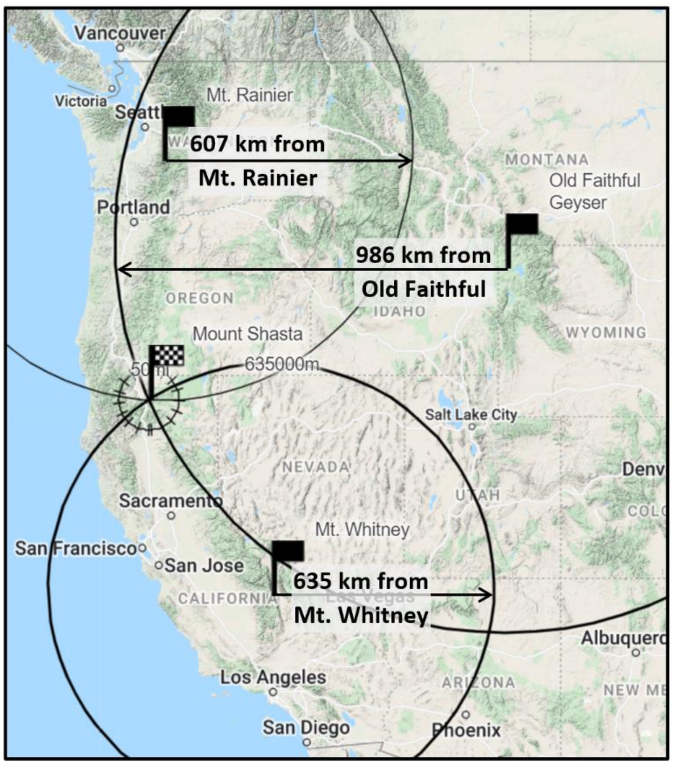


Fig. 5-1. *GPS mechanics.* To achieve the remarkable location accuracy of GPS, the time delay from each satellite must be computed with extraordinary accuracy. While each satellite contains an atomic clock of near-perfect accuracy, our cell phones and dedicated GPS devices do not. And since light travels 186 mi. (300 km) each millisecond, the clocks in our phones and other GPS devices are not up to this task without assistance.

Help arrives in the form of a "PRN code" broadcast uniquely by each GPS satellite. The PRN code, a unique binary sequence transmitted by each satellite, helps the receiver align its less accurate clock with the satellite's precise atomic clock. This alignment allows the measurement of the time delay of each signal's arrival within a few tens of nanoseconds and, consequently, for high-accuracy distance calculations to each satellite.

GPS example. Imagine you do not know your location but know you are, as shown in Figure 5-1: 1) 607 km from Mt. Rainier, 2) 986 km from the Old Faithful Geyser, and 3) 635 km from Mt. Whitney. Since you know the location of those three features, you could draw three circles around them using their distance as the radius. You know you are someplace on each of these

[14] The BeiDou system includes satellites in both Geostationary Earth Orbit (22,236 mi. or 35,786 km) and medium earth orbit.

circles, and there is only one place where you can be on all three. Your computations would show that the three circles intersect at one point, Mount Shasta, California!

This two-dimensional example computes our location from knowing our distance from three known points. This computation, called trilateration, differs from the angular computations we make with map and compass. The GPS device does not know or need the direction of the signal, only the distance to and position of each satellite, here represented as Mt. Rainier, Old Faithful, and Mt. Whitney. In addition to calculating position, as in the example, GPS devices compute the “Z dimension” or elevation to give a point in three-dimensional space, not necessarily on the earth's surface. For this computation, a minimum of four satellites is needed. Knowing the distance from additional satellites increases precision.

GPS ACCURACY AND ERROR

Early GPS devices were limited to the singular United States GPS system and, therefore, fewer lower-powered satellites than are available today. In addition, until May 2000, the signal was intentionally degraded for civilian use, further reducing GPS precision.

The older United States and Russian GPS systems have since been upgraded to the latest technologies, while other countries have developed the newer systems mentioned above with the latest advances. The result is that far more satellites are now available at any moment, broadcasting stronger signals on multiple frequencies.

Meanwhile, newer phones and other GPS devices now make their location computations based on three or more of these systems. This has significantly improved the accuracy and coverage, especially in challenging areas such as canyons and dense forests. While at least four satellites are needed for a position “fix,” unobstructed skies allow modern GPS devices to crunch data from over fifty satellites from those overhead at any one time. All GPS apps and devices estimate the current level of accuracy, typically giving coordinates plus or minus a number of feet or meters. With good conditions, such accuracy is often within 12 ft (4 m), far more accurate than is necessary for backcountry navigation. Such an accuracy estimate would mean that the actual coordinate or horizontal error should be 12 ft (4 m) or less 95% of the time. Elevation or vertical accuracy is roughly 1.5 to 3 times less precise than horizontal accuracy. A given 12 ft (4 m) accuracy means the vertical accuracy would be 18 to 36 ft (5 to 11 m) or less, 95% of the time.

Nevertheless, GPS errors persist for three primary reasons. First, mountains or canyon walls can physically obstruct satellite signals. Second, such physical obstructions may block a direct signal but allow a reflected signal to reach the GPS device, increasing the time of flight and causing inaccuracy. Third, while clouds and rain have negligible effects on GPS signals, solar storms can affect the ionosphere and cause it to slow the GPS signal more than usual. Occasionally, errors can cause your apparent position to jump hundreds or thousands of feet or meters to an incorrect location. While GPS accuracy has increased significantly, it is essential to maintain a high level of situational awareness and not follow the GPS device unchallenged. In

Fig. 5-2. ***GPS Form Factors:*** *a, Gaia GPS Phone app; b, CalTopo Phone app; c, Garmin dedicated GPS device with inReach capability; d, Smart Watch.*

other words, trust but verify.

GPS DEVICE FORM FACTORS

Phone apps. Before modern cell phones, a "GPS device," also known as a "GPS receiver," was a dedicated handheld device. Today, the GPS phone app is the overwhelming form factor for a GPS device. See Figure 5-2. All modern phones contain GPS chips that can access at least the US GPS system and the Russian GLONASS GPS systems anywhere outside; no cell towers are required. Most also contain chips to power a magnetic compass and a barometric altimeter. While some phones have screens the size of small tablets, all comments about phones also apply to tablet computers that commonly have GPS, altimeter, and compass chips. Innovative apps allow users maps to download maps via cell towers or Wi-Fi and can overlay waypoints, routes, and the ever-helpful you-are-here arrow. Phone GPS apps can access global map coverage with hundreds of general and specialized maps, satellite images, and overlays that are easy to download and typically free or low cost. Touch screens support intuitive menu structures but are challenging to use in the rain. During its first three decades, the cell phone could not transmit information via satellite, only cell towers and Wi-Fi. An inexpensive chipset debuted in 2023, which should make texting via satellite standard in phones.

Dedicated GPS devices. Several companies used to manufacture dedicated handheld GPS devices, but today, there is only one, the multi-billion-dollar Garmin Ltd. Company. Despite only one remaining manufacturer and diminished retail shelf space, these products still have a purpose. Dedicated handheld GPS devices are rugged, work better in low temperatures, and most use buttons or joysticks to allow for easy functionality, even in the rain or while wearing gloves. Garmin has added their inReach two-way satellite communication technology to some devices, allowing them to serve as a GPS device with digital maps, an altimeter, and a satellite communicator, three of the five required navigation devices. We will cover SATCOM devices in Chapter 7. In contrast to phone apps, dedicated GPS devices have a limited number of map types that are expensive and inflexible, requiring physical tethering to a computer for downloads. For example, purchasing all the detailed maps for just the United States would cost hundreds of dollars. Some free maps can be obtained online, but installation is not user-friendly. Most users tolerate the pre-installed maps. Even those intrepid souls who carry dedicated GPS devices typically still bring their phones as their primary navigation device, camera, and entertainment system. Dedicated GPS devices may cost from $200 to $700.

OUTSIDE OF PHONE COVERAGE?

Phones are walkie-talkies tuned to send and receive radio signals from millions of cell towers scattered across the globe. Outside of cell tower coverage, we cannot make calls, but anywhere we can see the sky, we can use the same antenna to detect the faint broadcasts of GPS satellites calling out their location. A specialized sliver of silicon at the heart of modern phones crunches the data in those whispers to trilaterate your location.

Smartwatches. The smartwatch is a growing consumer electronics category focusing on fitness tracking. They count steps, reps, and heartbeats for various sports. Some can serve as navigation assistants, providing altitude, GPS coordinates, and even tiny maps. Their keyhole view of the world functions best as a backup or auxiliary to a phone app or dedicated GPS device.

Apps and Maps

GPS APPS

While the satellite sorcery of our GPS systems allows us to pluck coordinates out of thin air, our GPS devices compile this data into actionable guidance. The GPS apps on our devices creatively compile the coordinates in useful ways. See Figure 5-3:

- **Waypoint (or marker):** A waypoint is a record of the coordinates of a location with optional additional data such as elevation, date, time, notes, or even a photograph. Waypoints can be retrieved later for viewing on a map or to generate a GPS bearing. Remember that the linear walk directly to a waypoint suggested by a GPS bearing is usually impossible or at least unpleasant, but the information is helpful. A waypoint could mark a parked car, a camp, a significant turn, or a bountiful patch of huckleberries.

- **Waypoint at the current location:** A GPS app can record a waypoint live at any location.
- **Waypoint for a remote location:** A GPS app can record a waypoint for a remote location. The user can long-touch the digital map and then name and save the waypoint. In addition, coordinates for any earthly location can be hand input from various sources such as a physical map, a guidebook, the metadata recorded with every digital photograph, or any other source.

- **Route:** A series of waypoints marking the anticipated way ahead is known as a route. A route can be created at home during trip planning, received over the internet during trip planning, or created in the field with the assistance of a digital map. A route can guide our footsteps and provide information about the path ahead, including distances, elevations, ascent and descent, slope steepness, and the types of land cover to anticipate, such as forest, barren, shrub, or ice. This information has always been present for keen map observers but is now at our fingertips.
- **Track:** Tracks are confusingly like routes but are actual recordings of a series of digital breadcrumbs or in-the-field waypoints you or others recorded on a GPS device. Tracks have higher fidelity with more waypoints as a record of every bend in the path, as well as meanderings and GPS errors. Since tracks also timestamp each waypoint, they can show numerous statistics about the route traveled, including distance, speed, moving time and speed, stopped time, and elevation profile.
- **GPX files:** All GPS device manufacturers have agreed on a few common file types to allow the exchange of waypoints, routes, and tracks. The standard format for most applications is the GPX file. Other formats include KML, KMZ (for Google Earth), and GeoJSON.

WILDERNESS-APPROPRIATE APPS

The author reviewed the most popular GPS apps and found that most lack critical features for wilderness navigation, such as:

- Download to your phone a wide variety of maps and overlays for offline use
- Set waypoints in the app for current and for distant locations
- Download routes and tracks for use in the app
- Create routes and record tracks in the app
- In-app choice of standard coordinate type (latitude and longitude, UTM) and datums (WGS84, NAD 27)
- Printing physical maps from a computer at various scales with grid lines.

The author recommends three phone apps for general wilderness navigation:

- Gaia GPS
- CalTopo GPS
- Garmin Earthmate or Explore (for use with Garmin devices)

While suitable for casual trail hiking, the author does not recommend the following two apps for wilderness navigation:

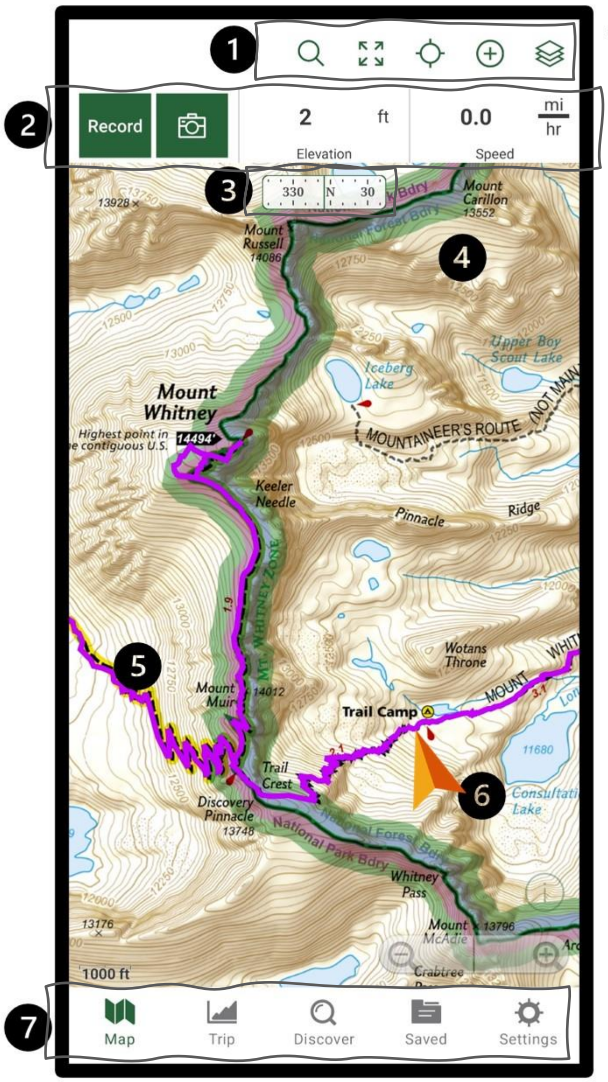
- AllTrails
- Komoot

For the author's latest list of wilderness-appropriate apps, please see the following link: [<<PLACEHOLDER FOR FUTURE LINK>>]

DIGITAL MAPS

The first GPS satellite was launched in 1978 aboard an Atlas rocket from Vandenberg Air Force Base. For many years, the output from GPS devices was extremely useful but simple data: location, speed, elevation, and GPS bearings. When GPS devices were married to digital maps, we entered the modern era of wilderness navigation. Today, a vast array of digital map types is available for download on our phones, typically for free or low cost. Dedicated GPS devices are usually limited to a single type of expensive map from the manufacturer, plus a haphazard patchwork of online maps.

Phone apps make downloading digital maps from the internet simple. For those who like a challenge and have the proper cable, digital maps can also be downloaded to dedicated GPS units. When a physical map is unavailable, a digital map can be used carefully as the primary map. Waypoints, routes, and tracks are all used to customize the physical maps you print and the digital maps that aid navigation en route.



Typical GPS App Functions:

1) Search places (points of interest, trails, and parks); show current location; create routes, add waypoints, download maps, import GPX files; choose among previously downloaded maps and overlays.
2) Record tracks; view current trip statistics such as elevation, speed, pace, sunrise, sunset, and current coordinates.
3) Compass.
4) The digital map.
5) Custom map elements: waypoints, routes, and tracks.
6) "You are here" arrow for current location.
7) App navigation including main map; current trip statistics; discover nearby trips; retrieve saved waypoints, tracks, routes, and maps; app settings.

Fig. 5-3. *Typical GPS app functions.*

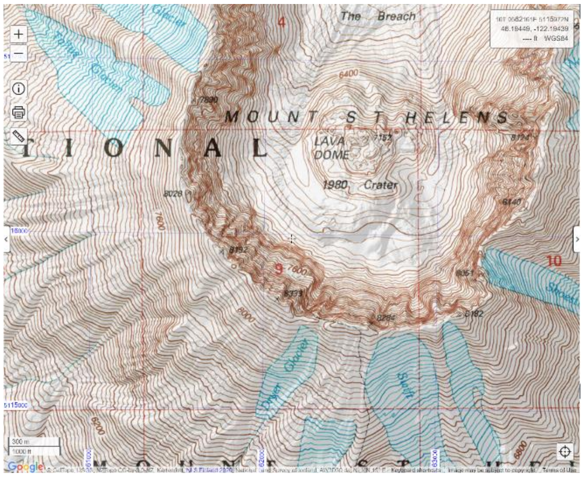
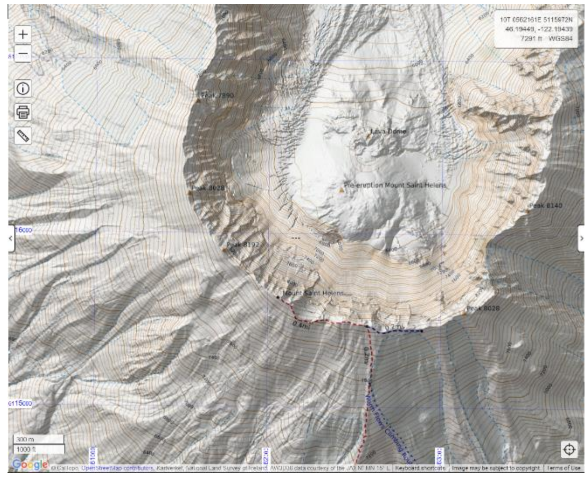
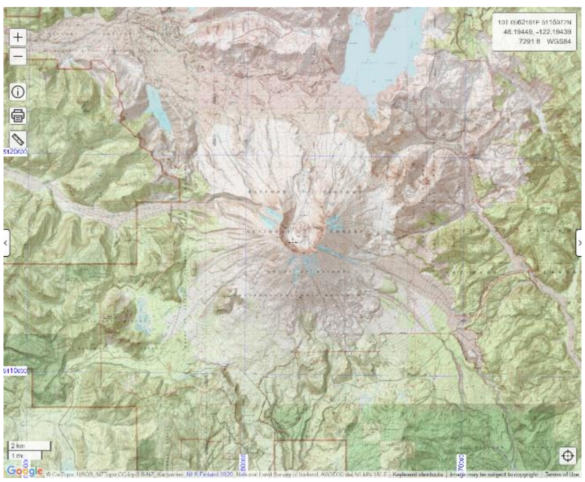
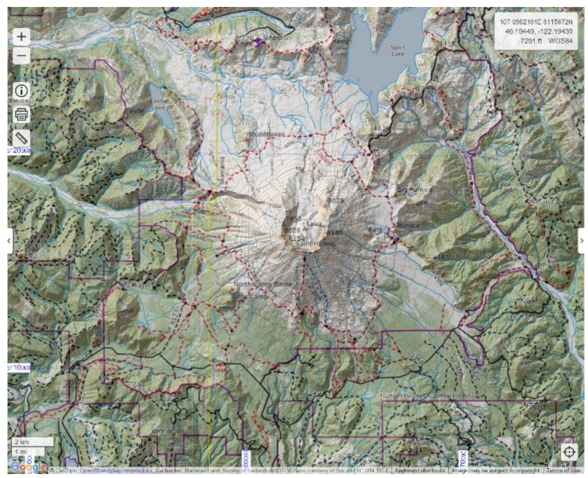
Mapping Methods

There are two basic methods for creating digital maps: raster and vector. Knowing the difference can be a huge help. A raster map is simply a static image, a high-quality scan of a physical map. These set the gold standard for elegance when used at the intended zoom level. But zoomed out, labels and trails on the raster map shrink until they are indecipherable. Zoomed out, the raster map becomes useless, like a map pinned to the wall across the room. Zoomed in too far, they are equally useless.

Vector maps are dynamic. Additional data, such as trails and peak names, may appear as vector maps are zoomed in to keep the map useful. As the map is zoomed out, the map sheds the now-tiny details like trails and the names of smaller lakes, while the names of major roads and towns appear.

Using maps of Mount Saint Helens, Table 5-1 illustrates the two digital mapping methods at a zoomed-in level and a zoomed-out level:

TABLE 5-1. COMPARISON OF THE TWO BASIC DIGITAL MAPPING METHODS.

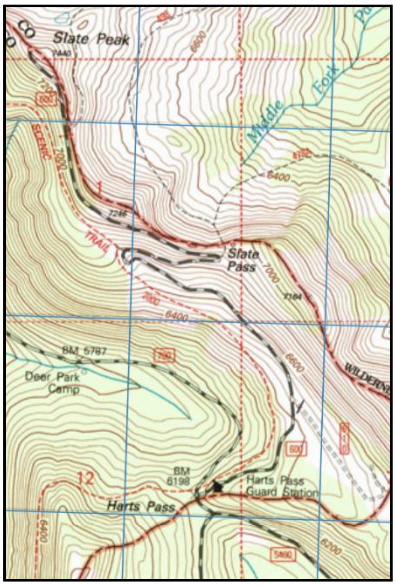
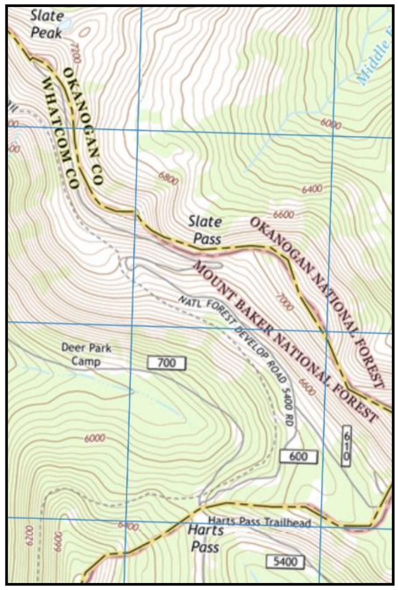
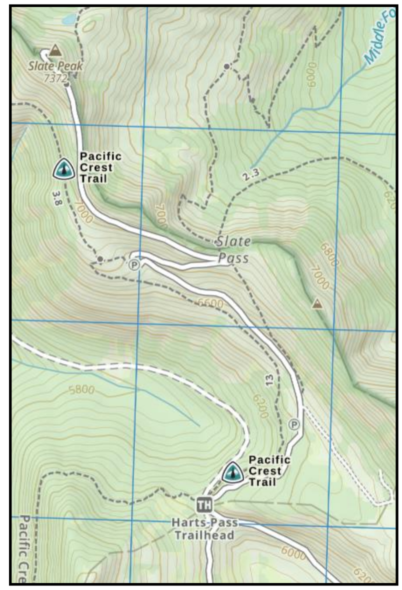
	Raster Map (Static)	Vector Map (Dynamic)
Zoomed In		
Zoomed Out		
	Advantages. These hand-drawn images are elegant at the intended zoom level.	**Advantages.** A much smaller download size, usually more up-to-date, remains useful when zoomed out, allows for snap-to routing, and allows field creation of detailed routes, often available in feet or meters.
	Disadvantages. A much larger download size, usually less up-to-date, useless when zoomed out.	**Disadvantages.** Map details are sometimes confusing to find when they are shown only at unexpected zoom levels.

Digital Map Types

For the map lover, we are in a golden age of maps. A pulp-free forest of map types is available for download to help us plan our next adventure. No map is equivalent to ground truth, but each map has a different part of the story. Here is a summary of the key digital map types:

- **OpenStreetMap (OSM).** OSM is an open-source collaborative project aiming to provide a free, up-to-date world map. Inspired by the success of Wikipedia, OSM has millions of volunteers who collect the necessary data to expand the map and keep it up to date. Feel free to get involved at OpenStreetMap.org. This crowdsourced world map, or database really, is available to anyone under a free license and is typically the most up-to-date map available. Most companies (e.g., Apple and Facebook/Meta) now build their maps based on the OSM database. Each company is free to emphasize different map elements to create a unique vector-based product that achieves the organization's goals, such as a map for hiking, biking, driving, or wheelchair access. GPS apps (e.g., Gaia GPS, CalTopo) typically offer a proprietary map based on the OSM database in addition to their other raster and vector maps.
- **USGS Topo (Historical) and US Topo.** The United States Geological Survey has been mapping the US since 1879 and is best known for its USGS 7.5-minute (1:24,000 scale, typically called a quadrangle or "quad") topographic map series. This original **USGS Topo (Historical)** series (1945 – 1992) was a hand-drawn product based on the work of field crews who hiked trails, classified natural features such as glaciers and swamps, researched boundaries, and interviewed locals for place names. In 2008, USGS began to define a new digital map series named **US Topo**. The US Topo maps are digital products produced using automated processes from mapping databases. While this current computer-driven approach is the right technology for our digital age, these database-driven maps lack the beauty of the handcrafted originals. In addition, details critical to the wilderness walker, including trails, parks, and boundaries, are incomplete in the database and the current maps. The work continues to flesh out the database as US Topo maps are being refreshed, but this work will take many years. In the meantime, the significant number of missing trails renders the USGS Topo (Historical) series a poor choice for trail hikers. See Table 5-2 for a comparison of OSM maps, USGS Topo (Historical) maps, and US Topo maps.

TABLE 5-2. A COMPARISON OF OSM AND USGS MAPS.

USGS Topo (Historical)	US Topo	OSM (Gaia GPS Topo)
		
USGS Topo Historical. This scanned raster-style map shows more trail detail than the US Topo but has a distracting border as its most prominent feature. These older Historical USGS maps use the older NAD27 datum*.	**US Topo.** This modern USGS vector-based map shows the national Pacific Crest Trail but is missing all the others. It still has an annoying border as its most prominent feature. Its roads and trails are light gray, making them the most difficult to read. These newer maps use the modern WGS84 datum* as the default.	**OSM (Gaia GPS Topo).** This OSM vector-based map from the Gaia GPS app shows the most trails, with trail detail significantly updated from the USGS Topo map. Overall, this map is the easiest to read and has the most up-to-date trail information. These newer maps use the modern WGS84 datum* as the default.

*A map's datum determines the placement of its grid lines. Datums are covered later in this chapter.

- **Satellite images.** Satellite images may not technically be "maps," but putting them in this category is helpful, especially when trails, roads, and other features are highlighted and named. Most satellite databases are assembled from cloud-free images taken over time, but some databases emphasize the freshest images taken weekly. Fresh images are especially helpful in determining the extent of the winter's snow remaining to help us decide whether crampons and ice axes will be needed. Some satellite images allow for astonishing clarity when zoomed in, which is occasionally helpful when navigation is tricky.
- **Activity-specific maps.** Maps are available tailored to hiking, camping, mountain biking, paddling, backcountry skiing, off-roading, hunting, and fishing, as well as maps for boaters and aviators, which they like to call charts.

- **Country-specific maps.** Mapping is typically viewed as a foundational function of governments, and many countries have made their national maps available to GPS apps (not always for free), including Canada, Mexico, Japan, Australia, New Zealand, Austria, France, Germany, Finland, Spain, Switzerland, Sweden, and the United Kingdom.
- **Informational maps.** While there are many maps available that are not appropriate for wilderness navigation, they can be helpful for trip planning. An example is a national park visitor map showing roads, parking, restrooms, picnic areas, and visitor centers. See Figure 5-4.

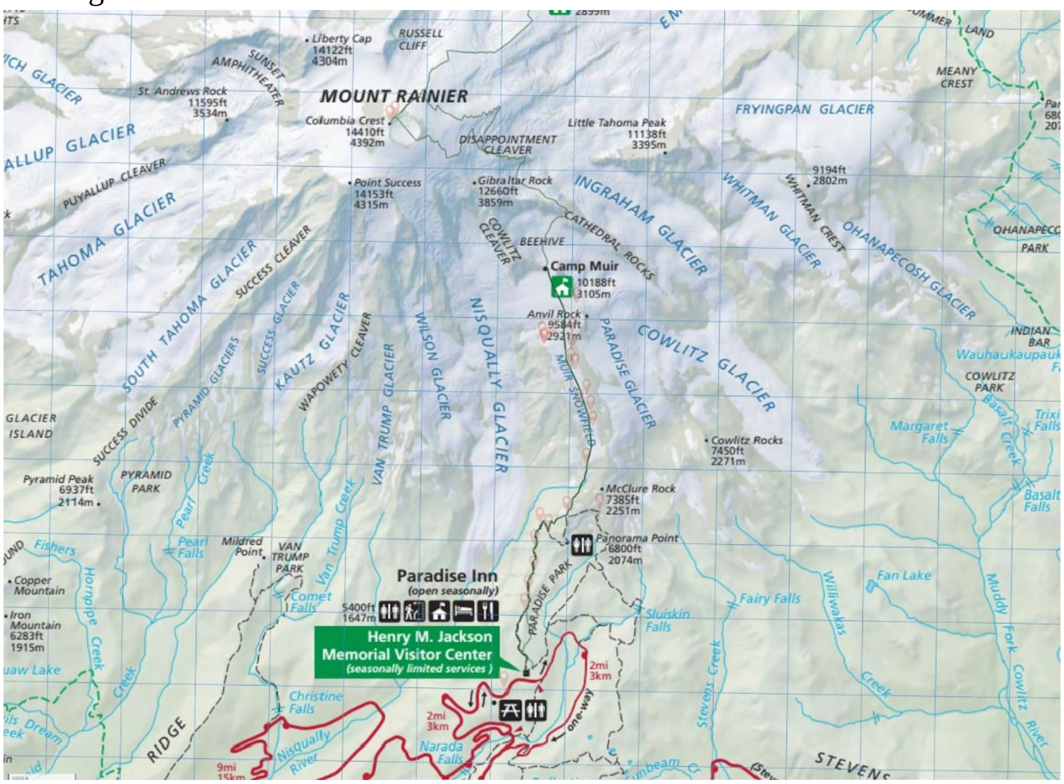


Fig. 5-4. ***Informational map for Mount Rainier National Park with UTM overlay.***

- **Historical.** Using outdated historical maps can thrill those who like hunting for abandoned trails, mines, and fire lookouts.

Digital Map Overlays

We must expand our definition of "map" to encompass a deluge of map overlays that add specific information types to our map for trip planning (which we will return to in Section III, Navigation Workflow) or while in the field. While a map tries to represent an area comprehensively, map overlays provide specific enhancements. Most overlays are used briefly to enhance the map during trip planning or in the field. Useful overlays include OSM tracks showing where others have traveled, avalanche forecasts, phone coverage, contour lines (for satellite images), precipitation and wind forecasts, slope angle shading, and shaded relief. Waypoints, routes, and tracks are also considered overlays and are typically used throughout the trip.

Downloading Maps to GPS Devices

Unlike a gourmet restaurant with a lavish menu, you do not need to pick a single entrée. You can download multiple map types and easily swap among them in the field. Your custom waypoints, routes, and tracks will remain atop any map type you choose as you cycle through your choices. Start by downloading the proprietary base map of your chosen GPS app, such as Gaia GPS's Gaia Topo or CalTopo's MapBuilder Topo. These OSM-based vector maps are fast to download, the most up-to-date, and optimized for the wilderness navigator.

DIGITAL DISAPPEARANCE

GPS phone apps allow internet-connected users to zoom in on any location. In the background, the app downloads the requested map tiles to temporary cache. Those tiles will remain in cache even if the phone is restarted. But cache is not a permanent download, and when new downloads exceed the space limitation, the new map tiles push out the old.

For a permanent map download, the user must define the area or specific tiles to be downloaded and then complete the download, which, under some conditions, can take hours. These maps will be listed in the app under saved maps.

Users failing to download maps correctly is a common source of failure and can make over-reliance on phones dangerous.

Language of Coordinates

As a Boy Scout, the grid lines on my treasured hiking maps were useless to me since I could not measure coordinates. We navigated as described in *Section I – High-Visibility Navigation by Sight,* using the foundational tools of the physical map and compass. We used observation, map reading, natural lines of position, and compass bearings. But now, we have GPS for exact measurements, so we need the language of coordinates to describe our location and grid lines to find our precise map position. Charles Pitman[15] of Summit County, Colorado Search and Rescue said, "If you have coordinates, you are golden to us. You really are. You're golden to us."

The two principal methods for describing precise locations on the earth are the latitude and longitude system, which originated in ancient Greece, and the UTM system, developed by the US Army in the 1940s.

[15] Out and Back Podcast, Episode 19

Latitude and longitude system. The latitude and longitude system is an embedded tradition of mariners and aviators who cover much greater distances than the wilderness navigator and whose maps cover hundreds of miles (or km) or more. Wilderness navigators using this system must cope with the system's complexity, which yields little benefit when traveling on pedestrian-powered scales. The system describes a location on the earth using angular measurements. A set of coordinates for latitude and longitude consists of three parts: 1) datum (which we will cover under UTM below), 2) latitude, and 3) longitude. Latitude (a parallel) is the north-south position measured by the degrees (zero to 90) north or south of the equator. Longitude (also known as a meridian) is the east-west position measured by the degrees (zero to 180) east or west of the prime meridian. The prime meridian has a longitude of zero and passes through Greenwich, England. See Table 5-3 for an example.

For example, The Mountaineers Seattle Branch is located at WGS84, 47°41'07" N, 122°15'51" W. This means using the WGS84 datum, The Mountaineers is located 47 degrees, 41 minutes, 7 seconds north of the equator and 122 degrees, 15 minutes, 51 seconds west of the prime meridian. As you might expect, there are 60 seconds (") in a minute (') and 60 minutes in a degree (°). In more human terms, this location sits on a latitude line (a parallel) that runs east-west around the world, slightly more than halfway from the equator to the North Pole. It also sits on the longitude line (a meridian) that runs between the North and South Poles west of the London-located prime meridian about two-thirds of the way toward the "opposite side of the world." This "opposite" lies 180° west or east of the prime meridian and is called the "antemeridian," which forms the basis of the International Date Line running down the middle of the Pacific Ocean.

Often, the N-S and E-W designators are omitted, and instead, positive numbers are used for latitudes north of the equator and negative for south. Similarly, positive numbers are used for longitudes east of the prime meridian and negative for west. The Mountaineers Seattle Program Center can be written as WGS84, 47°41'07", -122°15'51". This book omits the N-S and E-W designators and uses positive and negative numbers, as is the

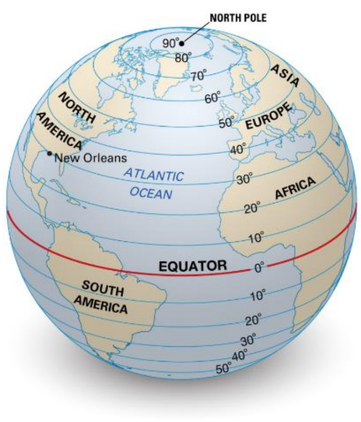
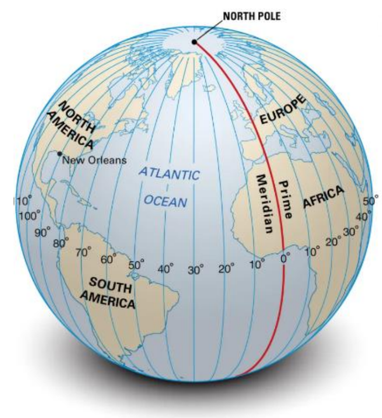
COORDINATES OF CONSEQUENCE

Listening to the radio at the Leavenworth ranger station, I could hear the rescue helicopter pilot as he touched down, "To whoever gave the coordinates for the LZ, well done!"

In The Enchantments, an area high in the Washington Cascades, in an era before cell phones or satellite communicators, we four hikers spent a snowy, restless night jammed into a two-person tent to keep our friend S. warm and alive. Finding her condition unchanged at dawn, my wife and I started the slippery descent of Aasgard Pass with mortal urgency. S. had collapsed the previous evening, strangely having lost her sense of equilibrium and ability to swallow, and was later diagnosed with stroke. It was nearly noon before we completed the snowy seven-mile, 5,000-foot descent to our car and drove to the ranger station. Bursting through the door to the head of the line to request a rescue helicopter, I knew we possessed a life-saving set of numbers—coordinates for our ailing friend and her husband, R.

convention for GPS apps and devices. Don't let it surprise you (as it did me!) that the absolute value of longitude numbers gets bigger as you go west (left) of the prime meridian, and the absolute value of latitudes gets bigger as you go south of the equator.

TABLE 5-3. LATITUDE, LONGITUDE, AND LOCATION.

Latitude	Longitude	Location
		
Latitude lines run east-west and form circles around the earth but indicate a distance, measured in degrees, north or south of the equator.	**Longitude lines** run north-south from pole to pole but indicate a distance, measured in degrees, east or west of the Prime Meridian.	**Example location.** Washington DC has a latitude of 39° north of the equator and a longitude of 77° west of the Prime Meridian. The location for DC is WGS84, 39° N, 77° W.

{artist, please change the globe to show Mountaineers in Seattle at 47° N, 122° W.}

Longitude lines are *long* because they always run from pole to pole. Counterintuitively, longitude lines tell you how far east or west you are, *but they run north-south.* Conversely, latitude lines tell you how far north or south you are, *but they run east-west.*

Inconveniently, the latitude and longitude system is expressed in three different formats. These examples are all for precisely the same location at The Mountaineers:

- Decimal degrees (DD): 47.68524, -122.26417
- Degrees and decimal minutes (DDM): 47°41.114', -122°15.850'
- Degrees, minutes, and seconds (DMS): 47°41'07", -122°15'51"

When looking at a map, latitude and longitude lines are awkward for estimating distances. Latitude lines try to behave by being equidistant at 69 miles (60 nautical miles or 111 km) per degree. Longitude lines are unruly since they continually get closer as they run north or south from the equator, converging at the poles. In addition, the three latitude and longitude formats quickly turn the arithmetic into a mess. Distances must be computed using a GPS device or the map's scale with a ruler or string.

UTM system. The fundamental problem with the latitude and longitude system is that it is not built on a regularly spaced square grid, making distance computations difficult, as noted above. UTM (or the meaningless "Universal Transverse Mercator") is a metric-based coordinate system built on a square grid to specify a location. For example, The Mountaineers Seattle Branch is at WGS84, 10T 555222E 5281579N. Occasionally, UTM coordinates are written with a small m to remind everybody the system is in meters. The coordinates of The Mountaineers would then be written WGS84, 10T 555222mE 5281579mN. UTM is always in meters, so this extra letter is unnecessary.

THE LONGITUDE–LATITUDE POEM

The longitude lines go up and down,
While the latitude lines go round and round

--Jacquie Eaton

A set of coordinates for UTM consists of four parts:

1) Datum	2) Zone	3) Easting	4) Northing
WGS84	10T	555222E	5281579N

1. **Datum.** Coordinate systems must be anchored to the earth by surveyed known control points known as a datum. While hundreds of regional datums are used worldwide (e.g., Borneo Datum of 1818), GPS devices are standardized on the global 1984 World Geodetic System (WGS84). When using a GPS device with a physical map, the device must be adjusted (under settings) to the same datum used by the physical map, shown in the fine print along the edge. Maps in the United States and Canada were produced under the North American Datum of 1927 (NAD27), and its continued use is surprisingly common. Here is an example of two sets of UTM coordinates that are identical except for their datums:
    - **WGS84** 10T 555222E 5281579N — Mountaineers Seattle Program Center
    - **NAD27** 10T 555222E 5281579N — Random location 217 meters away at north-northwest

As you can see from the example above, using an incorrect datum (reading a WGS84 datum on a NAD27 map) near Seattle results in an error of 217 m. This is a typical error in North America (the only place NAD27 is relevant). On the US West Coast, if you measure WGS84 coordinates on a NAD27 map, the result will be a point on the map about 150 to 200 meters too far north and 80 to 100 meters too far west. This error will be larger in

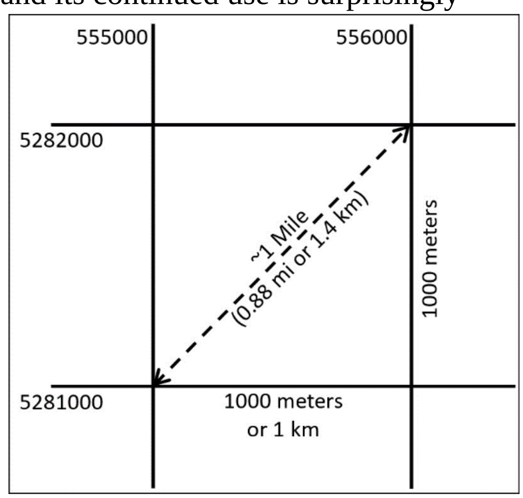


Fig. 5-5. *Map grid diagonals. Maps using UTM grids commonly use 1000-meter grids. Each side of the grid is 1 km, and the diagonal is about 1 mile (0.88 miles or 1.4 km). The diagonal for 2000-meter grids is about 2 miles (1.76 miles or 2.8 km) and about one-half mile (0.44 miles or 0.7 km) for 500-meter grids.*

western Canada, Alaska, and Hawaii and less on the North American East Coast. If you make the opposite error by measuring coordinates on a NAD27 map and inputting the coordinates into a GPS device erroneously set to WGS84, your errors will be in the opposite direction. *Datum choice errors have been blamed for some of the deadliest friendly-fire accidents in US conflicts, including the Persian Gulf War and the War in Afghanistan.*

As used here, datum means "horizontal datum," although maps also have vertical datums to define sea level. For all practical navigation purposes, ignore vertical datums. Digital maps do not have fixed datums, but they will display and adjust grid lines to the datum requested under the GPS device's settings. Using the wrong datum with latitude and longitude coordinates will produce errors different from UTM, even in the same locations.

For complete accuracy, we show the consistent use of the datum in all coordinates. In practical use, especially as NAD27 becomes less common, the WGS84 datum is assumed without being written or spoken.

Datums
The key is to set your GPS device to the same datum as your physical map.

2. **Zone[16].** The first exposure to zones in the UTM coordinate system may be confusing, but for most wilderness navigation situations, a zone is much bigger than our activity area. Zones in the mid-latitudes, such as the United States or Europe, are hundreds of miles or kilometers wide and stretch nearly from pole to pole. When the idea of a zone evaporates, we are left with a simple-to-understand and simple-to-use rectangular coordinate system where the north-south lines are called *eastings,* and the east-west lines are called *northings.* See the following two sub-sections.

   The UTM system divides the earth into zones numbered 1 through 60, each 6 degrees wide and stretching between the polar regions, which use a separate system. Zone 1 starts at the antemeridian, longitude 180 (east or west, they meet here), and covers 6 degrees toward the east; Zone 2 covers the next 6 degrees, and so on until zone 60 abuts Zone 1. See Figures 5-6 and 5-7.

[16] "Zone," as used in navigation, has two meanings. Here, a zone is a component of the UTM system. Do not confuse this with zone, as introduced in Chapter 2, meaning an area bounded by LOPs.

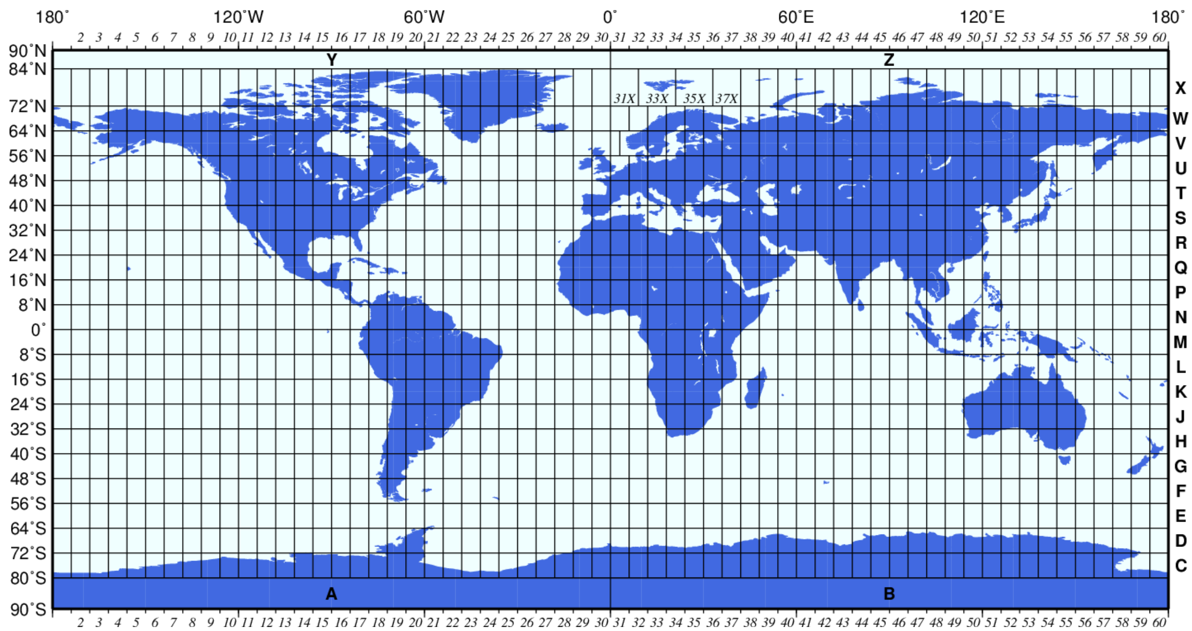


Fig. 5-6. *The world's 60 UTM zones. [Artist note: Simplify the graphic by eliminating most latitude markers on the left-hand edge. The equator and prime meridian should be noted and shown with bold lines. Perth and Kropotkin should be labeled and shown.]*

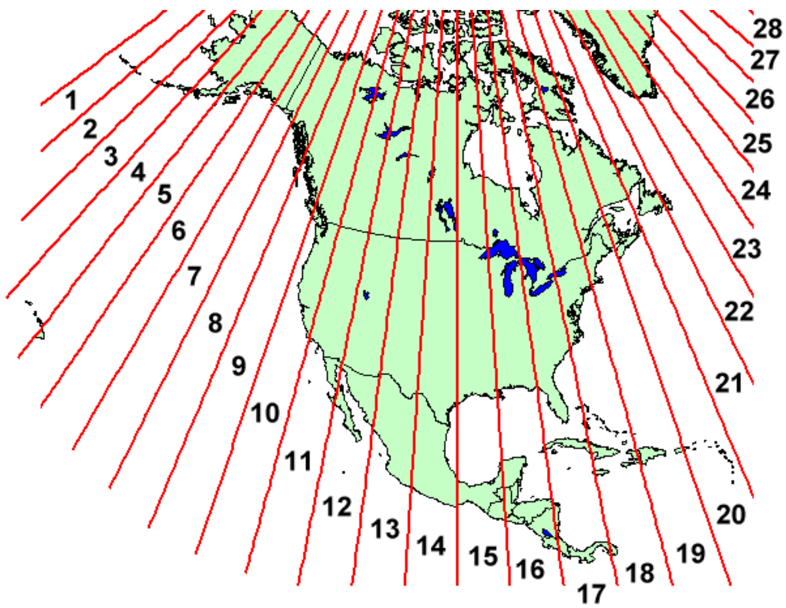


Fig. 5-7. *UTM zones for North America.*

{Artist note, 1) Exclude Greenland and everything below mid-Mexico. Limit to 22 zones. 2) Use a similar graphic for Europe and Australia/NZ if these markets are important.}

3. **Easting.** An easting is a measure (somewhat like longitude) of how far east-west a location is within a zone. The middle of each of the 60 UTM zones is arbitrarily set as an easting of 500000 meters. (UTM never uses commas and is spoken "five-zero-zero-zero-zero-zero." See below.) Eastings are always positive numbers and always have six digits (although some GPS devices confusingly start eastings with a zero, giving them seven digits). Having an easting of greater than 500000 simply means you are east (measured in meters) of the midpoint of the zone. An easting of less than 500000 means you are west

of the midpoint. Zones are the widest at the equator at 667,000 m (667 km or 414 mi) and narrow as they approach the poles. There is no "westing."

4. **Northing.** A northing is a measure (somewhat like latitude) of the distance north, measured in meters, from the equator or South Pole. Northings are always positive numbers and always have seven digits (except just north of the equator or Antarctic circle, although GPS units will fill in the leading digits with zeros to keep it seven). In the Northern Hemisphere, northings are zero at the equator and increase northward. Technically, northings start at 10 million in the Southern Hemisphere at the equator and decrease southward. Still, it is conceptually easier to think of northings as the "number of meters north of the South Pole or north of the equator." There is no "southing."

Vive Le Mètre

In 1791, amid the guillotining and deposing of royalty, the French Academy of Sciences took time away from the French Revolution to define the meter. They decided the distance from the equator to the North Pole would measure as 10 million meters, thus making it a convenient unit for navigation and, later, for the northing.

Due to extreme distortion in the polar regions, northings that would put you in the Arctic (above 84 degrees north latitude) or Antarctic (below 80 degrees south latitude) use a different system called the Universal Polar Stereographic (UPS) coordinate system.

Latitude bands. Frequently, but optionally, zone numbers are appended with a letter to indicate a location's distance north. The alphabet starts in the Antarctic with bands A and B, reserved for the UPS coordinate system mentioned above. The UTM system then starts with the letter C and continues north, using 20 letters from C through X, ignoring the confusing I and O. Bands Y and Z are reserved for the Arctic under the UPS system. See Figure 5-8 below.

These horizontal bands span 8° of latitude to indicate the approximate distance north for a location and, for the discombobulated globetrotter, whether you are in the northern or southern hemisphere since a single northing can be in either. For example, Perth, Australia, and Kropotkin, a small town in Eastern Russia, both have the same northing due to their distance from the south pole or equator, respectively. Although 10,000 km apart, the cities are precisely north-south from each other and share the same easting and zone. Their UTM coordinates are the same except for the latitude band. See Table 5-4.

Latitude bands, confusingly, are not part of the latitude and longitude system. Also, since they are redundant with the northing describing distance north, they are considered optional. See an exception in the next paragraph.

TABLE 5-4. LATITUDE BANDS.				
Location	Datum	Zone	Easting	Northing
Perth, Australia	WGS84	50J	392386E	6464284N
Kropotkin, Eastern Russia	WGS84	50V	392386E	6464284N

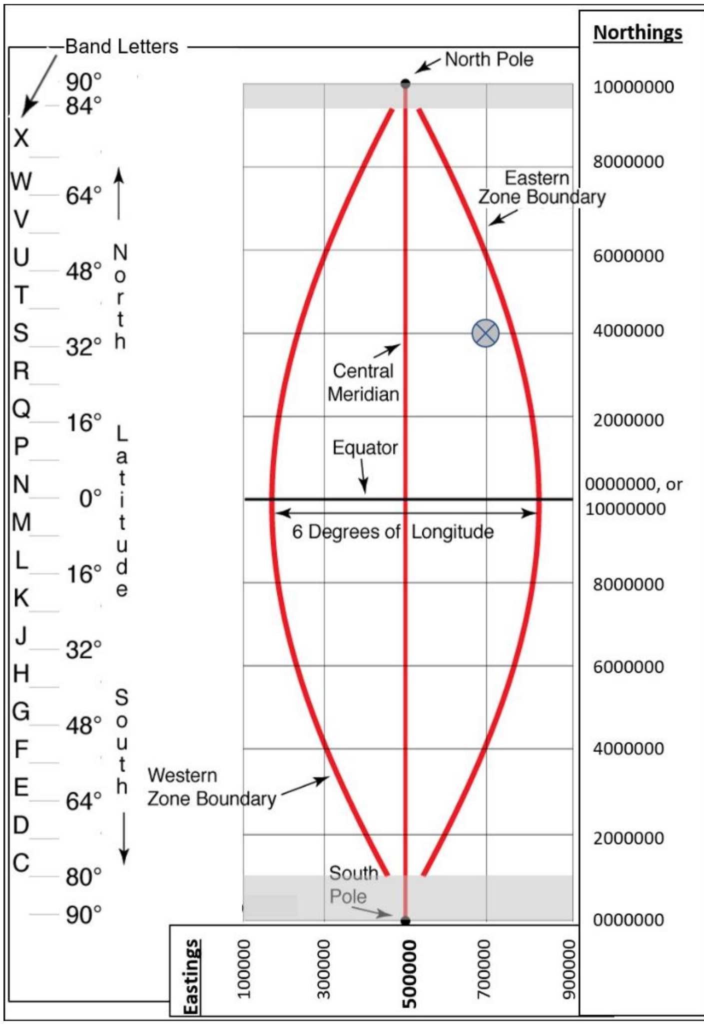
What hemisphere am I in? While hopefully not a practical problem for those on foot, each set of easting and northing in the Northern Hemisphere is repeated, 10 million meters to the south, in the Southern Hemisphere. To guide the confused, zones can be appended with a letter (see the right-hand edge of Figure 5-6 above). Letters A through M indicate one is in the Southern Hemisphere. Letters N through Z indicate one is in the Northern Hemisphere. Alternatively, some software appends a minus sign for the Southern Hemisphere. For example, Zone 32 is in the Northern Hemisphere; Zone -32 is in the Southern.

All together now. The architects of UTM created a solution to the millennia-old problem of creating a flat map for a sphere by forcing a square metric grid onto a long, skinny slice of earth. While this creates northings that do not point exactly north, the grid, typically 1000 or 2000 m on a side, makes for easy distance measurements on a human (or perhaps battlefield) scale. The general architecture of each of the 60 UTM zones is illustrated in Figure 5-8 below.

Dude, Where's My Van?

I once hired a guide to drop us at the trailhead and then drive our van to our expected destination after a two-week section hike of the trailless Sierra High Route. The guide promised to send me the exact UTM location where he parked, but his inReach message reversed the easting and northing. His error was obvious since eastings always have six digits and northings always have seven.

Easting first, then northing. In algebra, you may remember working with coordinates in the form (X, Y). The X-axis gauges how far east-west you are on the Cartesian plane, like an easting, and the Y-axis tells you how far north-south you are, like a northing. Over and then up, X and then Y, easting and then northing, six before seven, and there's your van.



In the Zone: Eastings and Northings

The meter was originally defined as one ten-millionth of the distance on the Earth's surface from the equator to the North Pole. Each zone is therefore 20,000,000 m long, stretching from pole to pole.

UTM is not used at the polar tips of each zone, as shown in gray. Because the earth is divided into 60 zones, each is 6° wide (360°/60 zones). The distance around the equator is twice as far as the distance fror pole to pole, making one equatorial circumnavigation about 40,000,000 m and each zone 666,667 m wide a the equator (40,000,000 m/60 zones). For clarity, the width of the zone in this figure is exaggerated by ten times; actual zone boundaries have a more gradual curve.

The center of each zone is arbitrarily assigned an easting of 500000, and once the square grid is superimposed on the zone, only this central easting (500000) points exactly north. At zone boundaries, th eastings can vary from true north by as much as 2°.

Example: The easting at the ⊗ is 700000 and the northing is 4000000. This example illustrates any zone but if it represented zone 29, the UTM coordinates would indicate a location a bit west of the Strait of Gibraltar and would be:

WGS84 29S 700000E 4000000N.

Fig. 5-8. *Architecture of each UTM zone.*

Derivative systems. Above, we addressed the two principal coordinate systems, the latitude and longitude system, and the UTM system. NATO militaries use the Military Grid Reference System (MGRS), which is similar to UTM. UTM is not used in the polar regions, so the Universal Polar Stereographic (UPS) coordinate system fills in the Arctic and Antarctic gaps.

Speaking of coordinates. For example, you will want to be clear if you ever need to speak a set of coordinates to search and rescue. While the map of choice for backcountry travelers displays the UTM grid, transmitting coordinates in "decimal degrees" (DD) under the Latitude and Longitude system will be the most widely understood in both spoken and written forms. No fussy degree or minute symbols are needed, and the US 911 emergency service is most likely to understand DD. Table 5-5 illustrates the particular way to vocalize coordinates under all the common systems:

TABLE 5-5. VOCALIZING COORDINATES

Coordinate System	Coordinates (WGS84)	Read As, " WGS eighty-four,…
UTM	10T 555222E 5281579N	…zone ten-T, 555222 east by 5281579 north."
MGRS/USNG	10T ET 55222 81579	…10TET, 55222, 81579"
Lat/Long: DD	47.68524°, -122.26418°	…47 point 68524 degrees north by 122 point 26418 degrees west."
Lat/Long: DDM	47°41.114', -122°15.851'	…47 degrees 41 point 114 minutes north by 122 degrees 15 point 851 minutes west."
Lat/Long: DMS	47°41'07", -122°15'51"	…47 degrees 41 minutes 07 seconds north by 122 degrees 15 minutes 51 seconds west."

Read the numbers without saying "hundred," "thousand," or "million." For example, say, "WGS eighty-four, Zone ten-T, five-five-five-two-two-two east by five-two-eight-one-five-seven-nine north." In critical situations, such as speaking to search and rescue, speak slowly and repeat the coordinates for clarity. Have the receiver also repeat the coordinates for verification.

Seagoing and aviation types use the NATO phonetic alphabet (Alpha, Bravo, Charlie, etc.). These folks have standardized on WGS84, so they rarely need to specify the datum. They would read the MGRS coordinates as "Zone ten Tango Echo Tango, five-five-five-two-two-two east by five-two-eight-one-five-seven-nine north."

As noted above, speaking or writing coordinates in "decimal degrees" (DD) under the Latitude and Longitude system will be the most widely understood. Four decimal places will give you accuracy to about 10 meters, so truncate the extra digits. Remember that a minus sign for latitude is read as "south," meaning south of the equator. A minus sign for longitude (as above) is read as "west," meaning west of the prime meridian.

Grid Lines: the critical link

Like the Lost Couple in the inset below, what if you have no digital map of your location? What if you have a set of coordinates from a guidebook, a photograph's metadata, or a phone app with no digital map? What if your treasure map has a set of coordinates to the pot of gold? How can you measure any of these coordinates on a physical map? The more general question is, "How do you connect the electronic world of GPS with a physical map?" The answer is the lowly grid line.

Fig. 5-9. *Map grid lines are the crucial connection between GPS and physical maps.*

Always print grid lines on maps. Grid lines are the critical link between the old world of physical maps and compasses and the new world of GPS and digital maps. See Figure 5-9. While my 12-year-old Boy Scout self in a pre-GPS world had little use for grid lines, printing grid lines allows the following:

- **GPS to map.** You are in a position like the Lost Couple (inset), where you find yourself without a digital map but have a physical map with grid lines. You are undaunted because you can set your GPS device to your physical map’s datum and grid line type. Your GPS device will give you a set of coordinates that you can find on the map.
- **Map to GPS.** You see a great camping spot on the map and want to hike there. You measure the coordinates on your physical map and manually input them into your GPS device. You are ready to go.
- **Guidebook to GPS and map.** Your guidebook gives you coordinates for a hike to an awe-inspiring view in a datum and coordinate system different from your map. You can set your GPS device temporarily to the datum and coordinate system of your guidebook and save the coordinates as a waypoint. Now, you reset your GPS device to your map’s datum and coordinate system. The GPS device will translate the coordinates to match your map. See “Translating Coordinates” below to learn how to convert coordinates (i.e., waypoints) between coordinate types and datums.

The lost couple in high visibility. So, what could our Lost Couple have done on that sunny day? If they had read "Section I – High-Visibility Navigation by Sight," they would have used all those methods, including:

- Orienting the map, with or without the compass.
- Navigate using natural lines of position and terrain recognition, including handrails and backstops.
- Locate themselves on the map by using the altimeter and compass.

Note that low-visibility techniques are also appropriate for high-visibility situations.

The lost couple in low visibility. Now, consider if our Lost Couple was hiking in the cloudy Cascades rather than the sunny Sierra. Then, high-visibility would likely have failed them. Having read Section II, they could have done the following:

- Anticipated the challenge at the trailhead by setting key waypoints as they hiked, whether on or off the trail.
- Recorded a track from the car. Following such a track would lead them back to the car with or without map grid lines.
- Maintaining high situational awareness, they could have noted the direction traveled (compass), elevations (altimeter), elapsed time, and notable geographic features, potentially recording these on the map.

By using these low-visibility navigation techniques, the couple could be confident of retracing their steps to the trailhead.

THE LOST COUPLE

During a multi-week hike in the trailless expanse of California's Sierra Nevada mountains, I encountered a young couple who was a bit lost. The woman had attempted to download digital maps, but her GPS app displayed only a blur and a set of coordinates (refer to the inset "Digital Disappearance" above). On the other hand, the man had meticulously created paper maps of the area but omitted grid lines, deeming them unimportant.

In desperation, they looked to me for assistance. How could they connect the GPS coordinates with their map? I gave them their current location on the map, an explanation of the importance of grid lines, and a few minutes of instruction on high-visibility navigation by sight, but I could do no more.

Locating UTM Coordinates on Maps

Typically, finding your position with a GPS device is simply looking for the you-are-here arrow on a digital map. But when you do not have the proper digital map, or you want to find the map location of coordinates for a place different than where you are standing with your GPS device, you need to locate coordinates on the map. Here, we will focus on locating UTM coordinates, the grid line choice for many wilderness explorers.

The edge of your map shows numbers that reflect the coordinate type used by your map. These numbers commonly label the map's UTM grid lines and the map's latitude and longitude tic marks. The map in Figure 5-11 uses labeled UTM grid lines and latitude and longitude tic marks.

Recall that in a set of UTM coordinates, eastings (which run vertically) are always after the datum (which is often omitted) and the zone but before the northing and typically followed by the letter "E." Eastings are always six digits (except when they start with an unhelpful zero, as on the map in Figure 5-10). Unlike longitudes, which increase from right to left west of Greenwich, England, eastings always increase from left to right on the map, from west to east.

Recall that in a set of UTM coordinates, northings (which run horizontally) are always listed last, after the easting, and are typically followed by the letter "N." Northings *always* have seven digits. Unlike latitudes, which increase as you get farther from the equator, northings always increase from bottom to top on the map, from south to north.

In this example, you climb Mt. Rainier in a whiteout and want to ensure you stand precisely on the summit. You have the detailed map from Figure 1-2 but no digital map. As you stand in the snow at what you believe is the summit of Mt. Rainier, the coordinates from your non-mapping GPS device at your current location read:

1) Datum	2) Zone	3) Easting	4) Northing
WGS84	10T	594508E	5189572N

Step-by-step guide for finding a UTM coordinate location on a map:

1. **Retrieve your GPS coordinates** from your non-mapping device (see examples under "#3. Coordinate-only (basic) GPS navigation"), noting that the format and datum are the same as your map**.** Coordinate-only GPS Navigation below covers why you would need to retrieve such coordinates and what to do if they are not in the same format and datum as your map.
2. **Measure your easting.** Find the easting grid line marked on the map, which is the rounded number just lower than the easting you are measuring. In our example, the easting is 594508, so the next lowest grid line is 594000. Our easting is 508 meters east of the printed line. Estimate[17] that distance based on the grid size, which is 1,000 meters here. Our easting is almost exactly halfway between 594000 and 595000. See Figure 5-10.
3. **Measure your northing.** Find the northing grid line on the map, which is the rounded number just lower than the northing you are measuring. In our example, the northing is 5189572, so the next lowest grid line is 5189000. Our easting is 572 meters north of the

[17] Estimates can be made by eye, by using your compass baseplate, or by using a separate plastic ruler calibrated for UTM map scales called a romer.

printed line. Estimate that distance based on the grid size, which is 1,000 meters here. Our northing is about 60% of the way between 5189000 and 5190000. See Figure 5-10.

4. **Your location is at your easting and northing intersection.** Congratulations, you have summited Mt. Rainier! As indicated on the map, the intersection of your easting and northing locates you on the precise summit.

This process can be done in reverse by starting with a location on the map. Estimate the easting and northing as in steps 2 and 3 above. When you append the datum and zone, you have a complete set of UTM coordinates.

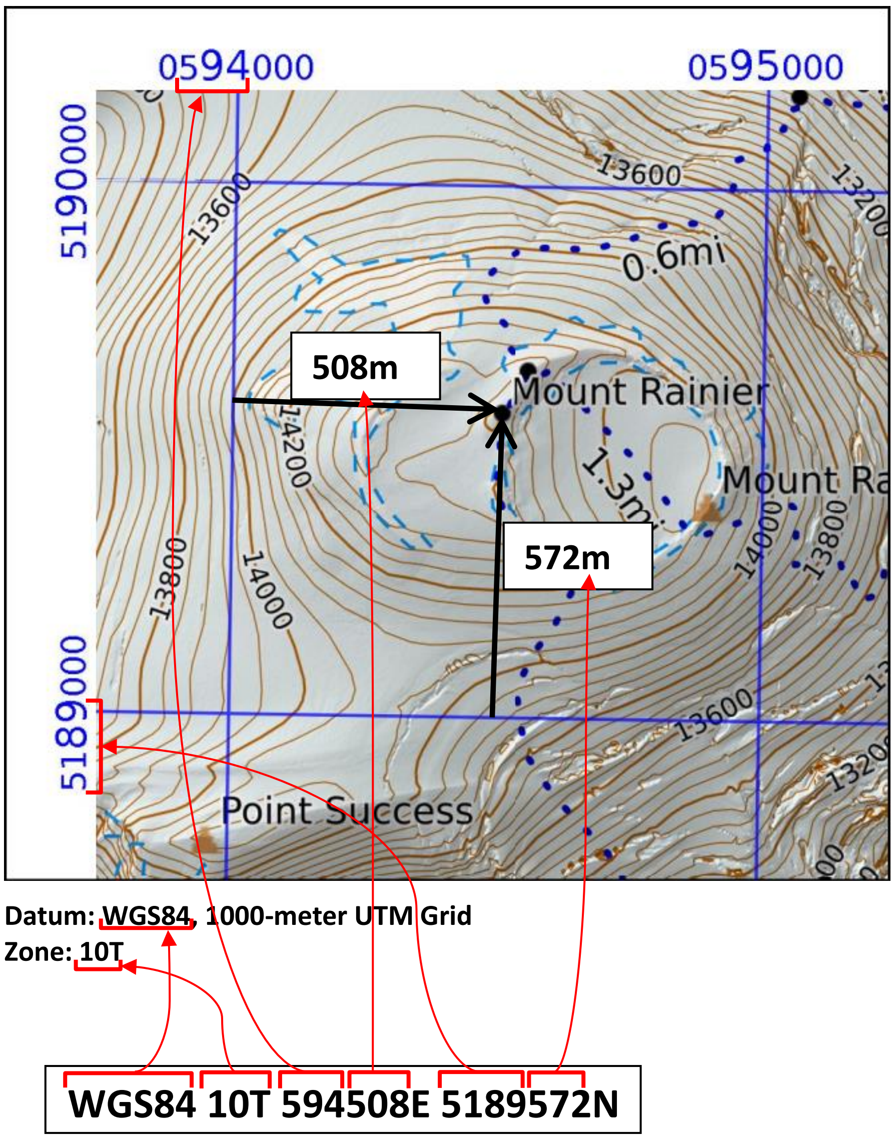


Fig. 5-10. *Detail of map shown in Fig. 1-2: UTM coordinates for the summit of Mt. Rainier, US.*

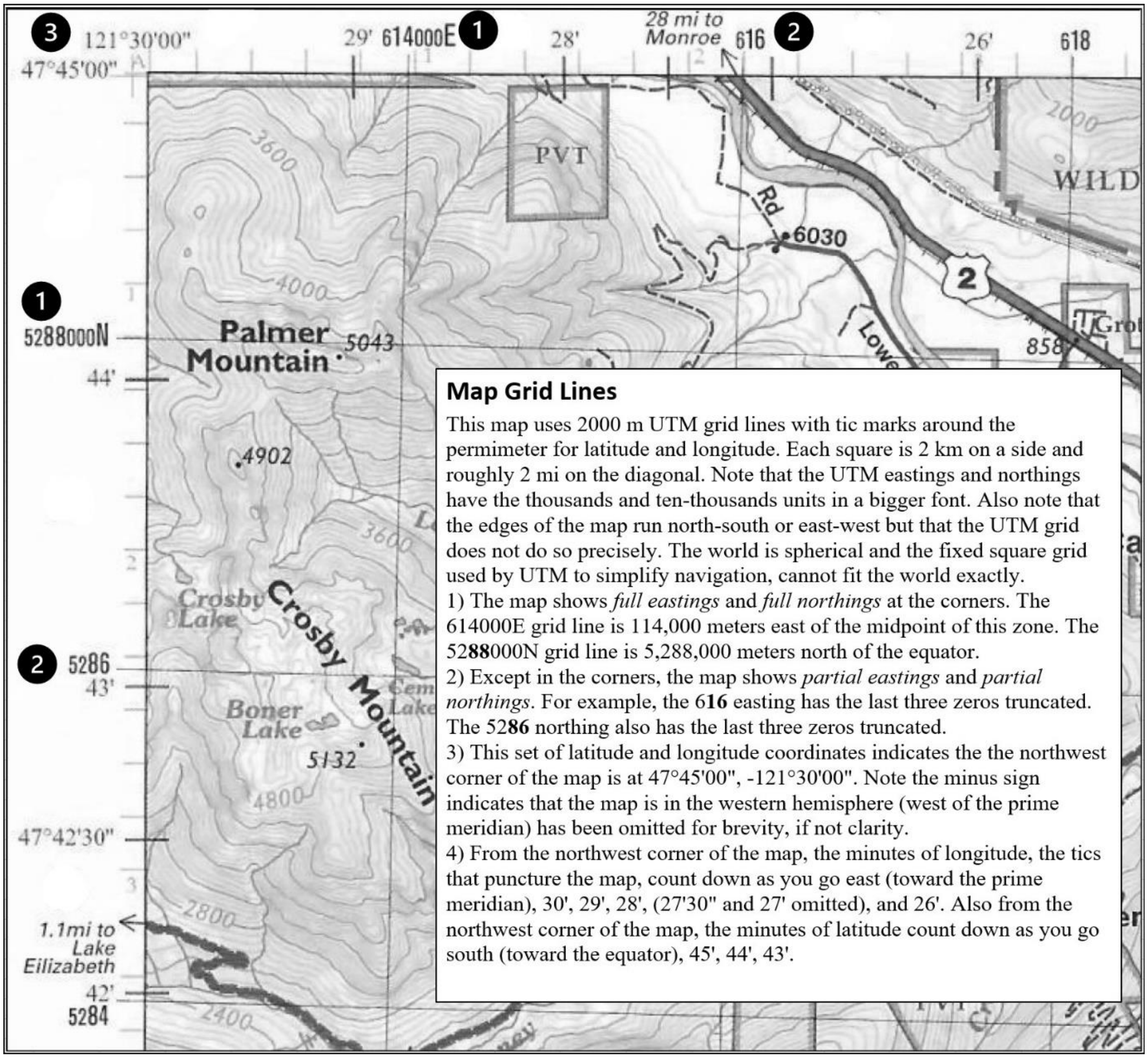


Fig. 5-11. *Northwest corner map detail illustrating grid lines. [Item #3 should read, "…Note the minus sign would indicate that the map is in the western hemisphere… Move Fig. 5-11 to two pages earlier.]*

Translating Coordinates

Standard GPS Device Coordinates

If you peer into the memory of any GPS device (or Google Maps), you will find that it has stored all waypoints (as well as routes and tracks, which are series of waypoints) using latitude and longitude in decimal degrees with the WGS84 datum. This simplification means that regardless of the device's settings when a waypoint is recorded or input, waypoints are translated to and stored using latitude and longitude in decimal degrees with the WGS84 datum. Waypoints, routes, and tracks can be displayed using any datum and coordinate type (grid system) chosen in settings. This is analogous to Excel storing a number as 25,404.9557 but displaying it as 25000, 25404.96, or 7/20/69 at 10:56pm. GPS devices easily translate coordinates from one coordinate type and datum to another.

Translating Coordinates

As you can see from Table 5-6 below, a precise location on the globe (here, The Mountaineers basalt climbing columns) can be described by various sets of coordinates that vary due to the choice of coordinate type and datum. Translating coordinates between coordinate types and datums can be critical when your map and another source (e.g., guidebook, coordinates from a photograph) disagree. Fortunately, GPS apps make the job easy. Most GPS devices allow the input of a waypoint using a variety of coordinate types and datums and then allow the waypoints to be translated and displayed using any coordinate type or datum chosen under settings.

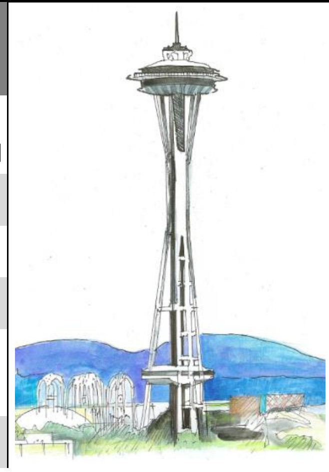
Here is the procedure for translating a set of source coordinates between different coordinate types and datums:

1. **Adjust to source.** Adjust the settings of your GPS device to the coordinate type and datum of the source coordinates.
2. **Input.** Create a waypoint in the GPS device by inputting the source coordinates by hand.
3. **Adjust to desired output.** Now, adjust the settings of your GPS device to the desired output coordinate type and datum. The coordinates will be translated for external display into the desired type, although they will always be stored using the abovementioned standard.

Example: Your guidebook of Seattle climbing hot spots lists the location of the Mountaineers Basalt Columns as WGS84 10T 0555222E 5281579N. These are your *source coordinates*. You want to find this on your older map, which is only marked in latitude and longitude DMS and uses the NAD27 datum:

1. **Adjust to source.** Based on your source coordinates (row 1), you adjust the datum in the settings on your GPS device to coordinate type to UTM and the WGS84 datum.
2. **Input.** You now record a waypoint on your device by manually inputting the source coordinates (10T 0555222E 5281579N).
3. **Adjust to desired output.** Now, adjust the settings on your GPS device to the output coordinates (row 5) required for your map: latitude and longitude DMS and the NAD27 datum. When you retrieve the waypoint, it now displays the translated coordinates (47°41'08", -122°15'47").

TABLE 5-6. GRANDFATHER'S FAVORITE FISH SPOT (Take your pick)		
Coordinate Type (Grid System):	**Datum:**	
	WGS84	**NAD27**
1) UTM	**Example translation :** 10T 0548893E 5274327N	10T 0548987E 5274131N
2) USNG/MGRS	10T ET 48893 74327	10T ET 48987 74131
3) Lat/Long DD	47.62050, -122.34931	47.62070, -122.34808
4) Lat/Long DDM	47°37.230', -122°20.959'	47°37.242', -122°20.885'
5) Lat/Long DMS	47°37'14", -122°20'58"	**Example source :** 47°37'15", -122°20'53"



Example: Your grandfather, a meticulous record keeper, noted in his journal in 1965 that his all-time favorite secret fish spot in Washington was at 47°37'15", -122°20'53", elevation 633 feet. You would like to find Gramps' fishing hideout on a map. Your grandfather's noted location are your *source coordinates* and due to their age (well before 1984, the origin or WGS84), must be using the NAD27 datum:

1. **Adjust to source.** Based on your source coordinates (Table 5-6, row 5), you adjust the datum in the settings on your GPS device to coordinate type to latitude and longitude and the NAD27 datum.
2. **Input.** You now record a waypoint on your device by manually inputting the source coordinates noted in Gramps' journal as latitude and longitude, DMS.
3. **Adjust to desired output.** Now, adjust the settings on your GPS device to the output coordinates (row 1) required for your maps: UTM and the WGS84 datum. When you retrieve the waypoint, it now displays the translated coordinates (10T 0548893E 5274327N).

Checking your Washington maps, you determine the coordinates are for Seattle's space needle, where the ground has an elevation of 133 feet. The restaurant soars 500 feet above the ground, for a total of 633 feet. You remember that Gramps was a joker, and he loved the salmon at the Space Needle Restaurant.

GPS NAVIGATION

Introduction

In Chapter 3 (see Figure 3-11), we introduced the idea of measuring and then using bearings with either a GPS device, a map, or a compass. There, we focused on measuring and using bearings with a map or compass. In this section, we will focus on measuring bearings with a GPS device and then using this bearing with:

- Your GPS device for **“On-trail GPS Navigation”**
- Your compass for **“Off-trail GPS Navigation”** or
- Your map for **“Coordinate-only (basic) GPS Navigation.”**

General GPS Tips

GPS navigation is a set of valuable tools and techniques for wilderness hikers and explorers. It is accurate, easy to use, and versatile. However, it is vital to be aware of GPS navigation's limitations and have a backup plan in case your GPS device fails.

GPS advantages. GPS navigation boasts numerous advantages over other navigation methods, including accuracy, ease of use, and versatility. GPS devices provide precise position information, even in low-visibility conditions. They are also relatively easy to use, even for beginners. Additionally, GPS navigation is flexible and can be accomplished through any of the three techniques listed above.

GPS disadvantages. Despite its merits, GPS navigation has certain drawbacks. Notable concerns include limited battery life, reliance on technology, and the potential for diminished situational awareness. GPS devices are battery-dependent, so carrying a charged power bank, the correct charging cable, extra batteries, or a solar charger as appropriate is essential. GPS devices are fragile electronic devices susceptible to physical and software failure. However, environmental factors have become less problematic due to the increased number of satellites, stronger signals, and better receivers. Nevertheless, poor reception caused by atmospheric conditions or blocked or reflected signals can produce faulty readings. Therefore, it is important to have one or more backup devices, a physical map, and a compass in case of GPS failure. Relying solely on a GPS device without a map or compass may lead to a loss of situational awareness.

GPS tips. These general tips can help prevent being disappointed by GPS:

- Start your trip with a fully charged phone.
- Make sure your GPS device has sufficient battery life and a supplemental power bank before starting your hike. In addition to putting your phone in airplane mode, review and

follow the other power-saving tips in Appendix 1, “Phone and Other Electronics Power Saving Tips.”

- Carry a backup GPS, map, and compass in case of GPS failure. Even without a cell phone plan, an older phone makes a great backup device. Phones carried by your team can be considered backups, but they need to have adequate power, the proper map layers downloaded, etc. **Click the find-me button** (Figure 5-12).
- Be aware of your surroundings and use your GPS device to supplement your navigation skills, not replace them.

When your device has sufficient power, the GPS app is not buggy, you have downloaded the correct digital map, and all the technology is cooperating, you then have a detailed topographic map that pinpoints your location and shows your direction of travel. This is GPS magic.

Introduction

For this section, we will assume that you have assembled four of the five tools of navigation: appropriate physical maps, digital maps on a GPS device, a compass, and an altimeter. The fifth tool, satellite communications, will be discussed in Chapter 6. We’ll also assume visibility is poor, perhaps no more than 100 yards (or meters), and therefore, GPS is the best navigation tool for these low-visibility circumstances. In the paragraphs below, we will discuss how to use On-trail GPS, Off-trail GPS, and Coordinate-only GPS navigation, and the advantages and disadvantages of each.

Here, you will learn each of the three GPS navigation methods. Each can be appropriate, depending on the situation:

#1. On-trail GPS
(Navigation using only a GPS device)

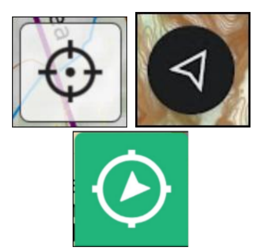


Fig. 5-12. Typical find-me buttons in GPS apps.

On-trail GPS navigation is the most straightforward method and is essentially how we navigate with Google Maps. It is especially suitable for well-marked trails and hikers new to GPS technology. It involves following a trail or route on your GPS device.

Tools used in this technique[18]:

1. **Your Prepared GPS Device:** Your properly prepared GPS device is all that is required. Ensure you have 1) a properly functioning device with plenty of power and backup power, 2) a wilderness-appropriate app, 3) the proper digital maps, and 4) a backup plan and tools.

[18] Every individual, or at least every party, should carry the five navigational tools on all backcountry adventures.

Step-by-step guide:

1. Open the GPS app or turn on your dedicated GPS device.
2. Click the find-me button (Figure 5-12). You should now have a detailed topographic map, pinpointing your location and displaying your direction of travel with a "you-are-here" arrow (Figure 5-13).
3. To make progress toward your destination, follow the map on your GPS device:
    - If the map has a trail, track, or route to your destination, follow the line on the map.
    - If there is no trail, route, or track, create a waypoint on your device at your target destination. Make progress toward your destination while avoiding difficulties. Creating additional waypoints for intermediate goals on the way toward your destination can be helpful.
    - Alternatively, create a waypoint at your destination (or an intermediate destination) and use the "Guide me" or "Navigate" function. As you move safely and rationally toward the waypoint, your app will continuously update the bearing and distance from the device's current location to that waypoint.

On-trail GPS navigation is simple and fast but comes with drawbacks. Frequent device use can tie up one hand and lead to high power usage and exposure to damage. Excessive screen use may result in a loss of situational awareness, making the navigator highly dependent on GPS.

While effective for navigating well-marked trails, be aware of the limitations of On-Trail GPS navigation and consider when the Off-Trail GPS technique might be more appropriate. Always have a backup plan for when your device fails, including Coordinate-only GPS.

#2. Off-trail GPS (navigation using a compass to follow a GPS bearing)

The most pivotal technique introduced in this book is Off-trail GPS navigation. Off-Trail GPS technique couples GPS with the compass and stands out as a transformative skill. Through numerous adventures, I've witnessed a paradigm shift in my increased reliance on the compass. This shift emphasizes Off-Trail GPS as an essential tool in contemporary navigation, seamlessly blending modern and traditional navigation instruments.

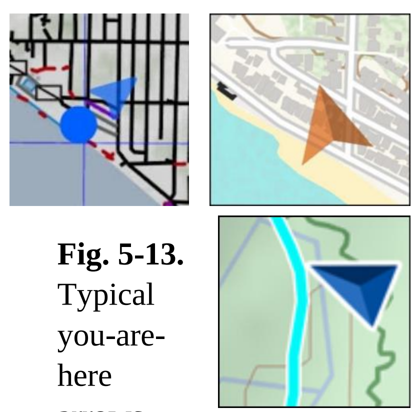


Fig. 5-13. Typical you-are-here arrows that indicate position and direction.

Best Suited for Cross-Country and Off-Trail Backcountry Adventures

Off-trail navigation presents unique challenges compared to on-trail experiences, requiring navigation of each step. The Off-Trail GPS technique, involving measuring a GPS bearing with your device and then using a compass to navigate, offers a swift and efficient method. This approach ensures a heightened situational awareness, minimizes battery usage, protects your GPS device, and enables using both hands for trekking poles or scrambling.

OFF-TRAIL GPS:
A GAME-CHANGING TECHNIQUE

A key revelation in effective GPS navigation is the enhanced usability of the compass when measuring bearings with GPS as the source. This insight significantly simplifies the navigation process.

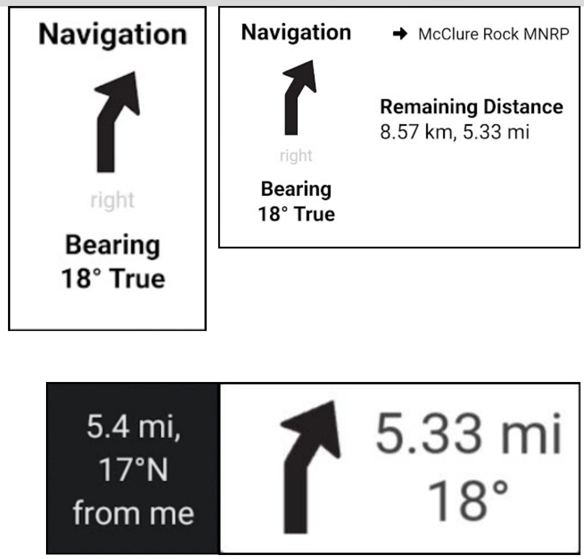


Fig. 5-14. Typical GPS bearing display in GPS App.

Tools used in this technique[19]**:**

1. **Your Prepared GPS Device:** Refer to the On-Trail GPS section for device preparation details.
2. **Declination adjustable baseplate compass:** Adjusted for local declination, as outlined in Chapter 3.

Step-by-step guide:

1. **Open the GPS app** or turn on your dedicated GPS device.
2. **Click the find-me button** (Figure 5-12). You should now have a detailed topographic map, pinpointing your location and displaying your direction of travel with a "you-are-here" arrow (see Figure 5-13).
3. **Measure a GPS bearing** to a waypoint at your destination or an intermediate destination using the Guide Me or Navigate function unique to each GPS app. You should see a GPS-bearing display similar to the samples in Figure 5-14.
4. **Set your compass to the GPS** bearing and find an object to keep in your line of sight as you move toward your objective. Put your phone away in a safe place and turn it off if necessary to preserve battery power. See “Navigating Nature's Obstacles” for advice on finding and following objects with a compass.
5. **Make safe, efficient progress** through the landscape, moving toward your objective by monitoring your compass. Monitor **your progress** as the distance component of the GPS bearing decreases. When uncertainty about your direction arises, loop back to step 3,

[19] Every individual, or at least every party, should carry the five navigational tools on all backcountry adventures.

assess the distance component of the GPS bearing, and remeasure your GPS bearing. Iterate until you reach your objective.

Key insight: The wilderness often presents obstacles, necessitating deviations from a straight line. Realize that any deviation affects the accuracy of the GPS bearing. As you prudently make progress, your app continually updates the bearing and distance to the waypoint.

Embark on your off-trail adventures armed with the Off-Trail GPS method that blends tradition with technology. This technique offers efficiency, situational awareness, and adaptability for a confident and successful off-trail journey. See Figure 5-15.

Figure 5-15. *The author, on day ten, southbound on the Sierra High Route, navigating around Mt. Ritter, 12,936', in the Ansel Adams Wilderness using the Off-Trail GPS technique. Photo by Ian Alvarez.*

#3. Coordinate-only (basic) GPS navigation (using a non-mapping GPS source and a paper map)

The core functionality of a GPS device has always been to calculate a simple set of coordinates at the device's location. Waypoints, tracks, routes, and you-are-here arrows displayed on geolocated digital maps are extensions of that core functionality. When your GPS device only yields a set of coordinates without a digital map, physical map grid lines become the critical link (see "Grid Lines: the critical link" above) between GPS and your physical map.

Tools used in this technique[20]**:**

1. **Non-mapping GPS device:** Devices include 1) a GPS device without the proper digital map installed, 2) a satellite communicator such as the Garmin inReach Mini, 3) a non-mapping GPS watch, 4) a vehicle with GPS, or 5) the location metadata from a photograph taken with a digital camera. For mapping a location that is not your current location, a source of coordinates could include a guidebook, a text, or a phone call from a lost student (see inset below, "The Lost Student.)."
2. **Physical map:** Your map must have grid lines, or this technique will not work. See the inset above, "The Lost Couple."

THE LOST STUDENT

I led a sport climbing trip at Exit 38 near Seattle on a summer evening. One of the students arrived late and decided to walk the mile from the cars to the climbing area on his own. He called me when he realized he was lost, but he didn't know how to retrieve his coordinates and had no GPS software installed.

I found the student, but the method involved yelling, wandering, and luck rather than an elegant solution.

Step-by-step guide:

1. Retrieve the GPS coordinates from your non-mapping device, noting the coordinate type and datum. (If no datum is noted, start with the much more common WGS84.)
2. If a) the coordinate type and datum of the coordinates retrieved from your device are different than b) the coordinate grid lines and datum of your map, translate a) into b) as detailed under Translating Coordinates above.
3. Locate the coordinates on your paper map using the map's grid lines.

You will not always have the proper digital map for the standard GPS navigation methods, but often, you will still have access to GPS coordinates. Coordinate-only (basic) GPS navigation is an excellent backup method for when your tools are not properly prepared, plans change, or the technology is not behaving.

Summary

Figure 3-11 showed us that bearings are measured (1) with a GPS device, (2) on a map, or (3) using a compass in the field. Then, these bearings are used with either (a) a GPS device to follow in the field, (b) a map to plot, or (c) a compass to follow in the field. In Chapter 3, we explored measuring and then using bearings with a map and compass.

[20] Every individual, or at least every party, should carry the five navigational tools on all backcountry adventures.

TABLE 5-7. NAVIGATING WITH GPS USING THREE METHODS (Each method is appropriate, depending on circumstances)			
	Trail GPS	**Off-trail GPS**	**Coordinate-only GPS**
Tools required:	Digital map plus you-are-here arrow	GPS Bearing plus compass	GPS coordinates plus physical map
Best for:	On trail casual use	Off-trail exploration	Backup
Advantages:	Dead simple Fast	Lower power usage Helps maintain Situational Awareness Phone/GPS device stowed, allowing use of hands	Works without a digital map Important backup technique Low GPS dependency High Situational Awareness
Disadvantages:	High power usage Requires frequent use of hands and fragile phone/GPS device High GPS dependency Easy to lose Situational Awareness	Requires understanding of how to follow a GPS bearing. Moderate GPS dependency	Slow Difficult to use on the move

Here in Chapter 5, we completed the set by exploring the measurement of bearings with a GPS (GPS bearings) and then how to use such measurement from a GPS device: a) by itself with a digital map, b) with a compass, or c) with a paper map. We call these methods a) Trail GPS, b) Off-trail GPS, and c) Coordinate-only GPS. For each method, Table 5-7 summarizes the tools required, the best use, the advantages, and the disadvantages.

Chapter 5 Conclusion

Chapter 5 unveiled the magic of GPS, our final navigation tool. We demystified its components, mechanics, and the science behind its pinpoint accuracy. From sleek devices to mobile apps, we explored varied formats and delved into routes, tracks, and GPX files. Digital map types and overlays provided the visual landscape, while coordinates in Latitude/Longitude and UTM systems unlocked the connection between digital data and physical maps. Finally, we learned the three GPS navigation methods: Trail GPS, Off-trail GPS, and Coordinate-only GPS.

Equipped with this knowledge, navigators can leverage the power of GPS to enhance situational awareness, make informed decisions, and conquer the wilderness with confidence and efficiency.

While GPS empowers, the wisdom of modern wilderness navigation lies in its blending with map, compass, altimeter, and keen observation. Embrace the symphony of skills and tools for safe and confident exploration.

Glossary

[All original text]

TERM	**DEFINITION**
agonic lines	Slowly moving lines on the earth at which declination is zero. These lines typically emanate from the north and south magnetic poles, serpentine around the globe, and then terminate at the North or South Pole, respectively. Agonic lines occasionally form as closed loops that do not touch the poles.
altimeter	An instrument for determining elevation using barometric pressure, GPS, or a location-based table.
amplitude	The variance in the direction of sunrise and sunset from due east and west.
back bearing	A bearing that is 180 degrees offset from the original bearing. It is measured by using the magnetic needle of a compass and setting it to the original bearing. The black end of the needle will then point in the direction of the back bearing.
backcountry	Remote, non-urban regions lacking easy access to transportation or emergency services, including forests, mountains, deserts, and other natural areas. These areas require specialized skills and preparation for safe navigation and self-sufficiency.
backstop	A LOP that runs crosswise to the direction of travel that alerts navigators of a turn or destination. Also known as a “catch line,” “catching feature,” or “baseline.”
bearing	A direction from one location to another measured in degrees from true north. Also known as a “true bearing.” A bearing is measured on a map (map bearing), measured in the field using a compass (compass bearing), or with a GPS (GPS bearing). The US army (but not the US Navy or the armies of other English-speaking nations) uses the alternative term “azimuth.” See also compass bearing, map bearing, and GPS bearing.
beta	Typically used by climbers, beta means data gathered about an area that may be crucial to the success of a climb. Beta may be gathered from alternate map types, guidebooks, websites, local officials, or previous

	visitors.
compass bearing	Is measured using a compass in the field. This term differentiates it from a map bearing and a GPS bearing.
contour lines; contour interval; index contour	**Contour lines** mark points of equal elevation on a map. Walking a contour line maintains a constant elevation. A **contour interval** is the elevation difference between contour lines. Typically, every fifth contour line is an **index contour** and is shown darker with the elevation indicated.
coordinate system	A geographic system to describe a location on the earth, such as UTM or latitude and longitude.
coordinates	A pair of lines of position, defined by a coordinate system, whose intersection defines a location. The two primary sets of coordinates are easting and northing, and latitude and longitude.
datum	Coordinate systems must be anchored to the earth by a set of surveyed known reference points and are (often) defined by a mathematical model of the earth's shape. Together, the set of anchor points and earth model are known as a geodetic datum (plural datums, not data). WGS84 is the standard datum for all GPS devices. Datums are important when using a map with a GPS device.
dead reckoning	A backup off-trail navigational technique that closely follows a map bearing as the line of position in a straight line from one known location to another without reference to visible landmarks, celestial bodies, or GPS. This originally nautical method is often challenging for land navigation where terrain can make straight-line travel difficult or dangerous. Compare with trail dead reckoning and live navigation.
death by GPS	An expression for the death of navigators who lose Situational Awareness by over-reliance on a GPS app or device. See also general loss of situational awareness. [Add an example, such as the person who used their total reliance on their car's navigation system that they drove right off the end of the pier.]
declination (also magnetic declination or magnetic variation)	The angular difference between the local magnetic field (i.e., magnetic north) and true north. This angular difference is expressed in degrees east or west of true north. This angle changes over time and varies based on location. For example, in Seattle, in 2023, a magnetic compass needle points east of true north (clockwise) with a declination of +15.3° or 15.3° east. In New York City, in 2023, a magnetic compass needle points west of true north (counterclockwise) with a

	declination of -3.3° or 3.3° west. "Magnetic variation" or "magnetic declination" are the terms preferred by mariners and pilots to differentiate it from the term "declination," which has a different meaning in astronomy and celestial navigation.
dedicated GPS device	A specialized handheld device designed for navigation purposes. These rugged devices excel in harsh environments, offering easy operation, even in the rain or while wearing gloves. These devices can incorporate two-way satellite texting, transforming them into tools that combine GPS, digital maps, digital compass, altimeter, and satellite communicators, covering the essential navigation tools.
digital map	A map is displayed on the screen of an electronic device, which is typically GPS-enabled, such as a dedicated GPS device or a phone or tablet with a GPS app. Come in two primary forms: raster and vector digital maps.
direction-of-slope method	Method to determine location (or several possible locations) using only a topographic map, an altimeter, and a compass, even in zero visibility. Also known as the "contour-tangent method."
easting	A measure (like longitude) of how far east-west a location is within a UTM zone. The middle of each of the 60 UTM zones is arbitrarily set as an easting of 500000 meters. Eastings are always positive numbers, always have six digits (although some GPS devices confusingly start eastings with a zero, giving them seven digits), and are written without commas. Having an easting of greater than 500000 simply means you are east (measured in meters) of the midpoint of the zone. An easting of less than 500000 means you are west of the midpoint. There is no "westing." See northing, UTM.
ethic of self-reliance	The principle of being adequately prepared, skilled, and independent for safe survival in wilderness environments. It emphasizes personal responsibility, encompassing the acquisition of navigation and survival skills, thorough trip planning, and appropriate gear selection. This ethic highlights the importance of autonomously solving problems and making informed decisions in remote, unpredictable outdoor settings.
elevation	The vertical distance above sea level or the ellipsoid, depending on the instrument. Modern GPS devices and most phone apps correct for the difference between the ellipsoid and sea level (geoid).
ellipsoid	A mathematical representation of the earth's shape used by altimeters to calculate elevation. The ellipsoid can vary by about +/-300 ft (90 m)

	from sea level.
fall line	The direction an imaginary bowling ball would take straight down a hill, perpendicular to the contour lines.
five tools of navigation	The five core tools considered essential for wilderness backcountry navigation are 1) physical maps, 2) digital maps on GPS device, 3) altimeter, 4) compass, and 5) SATCOM.
follow a GPS bearing	See live navigation.
general (or gross) loss of situational awareness, GLSA	Describes geographic and spatial disorientation, failure to perceive hazardous conditions or anticipate changes, and a lack of confidence in instruments, which contribute to compromised decision-making abilities. Exacerbated by ambiguous situations, distraction, fatigue, confusion, and a breakdown in communications.
GLONASS	(See GNSS)
GNSS	GNSS (Global Navigation Satellite System) is the generic name for any global satellite-based navigation system. These systems include the US Global Positioning System (GPS), the Russian GLONASS system, the European Galileo system, and the Chinese BeiDou system. (See GPS).
GPS	GPS is an acronym for the Global Positioning System of the US Air Force. In everyday use and this book, GPS refers to a GPS device, the various GNSS collectively, or something that uses these systems (e.g., GPS navigation, GPS bearing).
GPS app	A phone or tablet app that combines digital maps with a device's GPS, compass, and altimeter capabilities to assist navigation. This combination is referred to as “GPS,” constituting one of the five tools of navigation.
GPS bearing	A bearing derived using a GPS device which includes both bearing and distance toward an objective. This new term differentiates it from a compass bearing or a map bearing.
GPS device	A GPS device is an instrument that can determine a location based on signals from GPS satellites. Its form is typically a phone, a specialized device, or a watch.
GPS receiver	An out-of-date term for a GPS device, used before such devices were integrated with digital maps.

GPS route and GPS track	GPS routes and tracks are similar. Both are a series of two or more waypoints recorded in a GPX (or similar) file. Routes are prepared in advance on a phone or computer, usually with fewer waypoints than a track. Tracks are a series of breadcrumb in-the-field waypoints recorded on a GPS device. Tracks have higher fidelity, with more waypoints as a record of each bend in the path, each meandering, and GPS errors. Routes and tracks are both used as custom map overlays to aid navigation. A route is sometimes called a line. Garmin sometimes calls them courses.
GPX File	GPX is a data file format for exchanging GPS data (waypoints, routes, and tracks) between GPS applications and devices. Other formats include GeoJSON, KMZ, and KML.
grid north	Many maps use a grid based on the northing, which can vary by up to about 2° from true north or the longitude. Map bearings from these maps would be based on "grid north." Frequently, both longitudes and northings are used on maps. Be intentional about which grid you use when measuring or plotting bearings with a map.
handrail	A handrail is a LOP that can be used to guide travel by sight (physical LOP) or instrument (instrument LOP)
instrument line of position	An instrument line of position (LOP) is a LOP that requires an instrument to measure. Instrument LOPs are elevations, compass bearings, or coordinates measured by an altimeter, a compass, or a GPS.
latitude and longitude	One of the primary coordinate systems. Latitude is the north-south position measured by the degrees (0–90) north or south of the equator based on angular measurements. Longitude is the east-west position measured by the degrees (0–180) east or west of the prime meridian. A full latitude and longitude coordinate consists of three components: datum, latitude, and longitude. For example, The Mountaineers Seattle Branch is located at WGS84, 47°41'07" N, 122°15'51" W. Latitude and longitude coordinates can be expressed in three formats. See Chapter 5, "Latitude and longitude system," for more details.
latitude band	Optional enhancement to the UTM system. UTM zones are frequently appended with a letter to indicate the approximate distance north from the South Pole. See Chapter 5, "Language of Position," for more

	details.
line	A series of waypoints designated as a route, track, trail, watercourse, bearing, or boundary.
line of position (LOP)	A physical LOP or an instrument LOP. The intersection of two or more LOPs is used to determine location. (Also known as a position line or reference line.) See physical line of position and instrument line of position.
live navigation; follow a GPS bearing	An emerging form of navigation that leverages real-time data to guide travelers to their destinations, primarily known to the public through such apps as Google Maps and Waze. In wilderness navigation, we "follow a GPS bearing" as a primary off-trail technique when straight-line travel is challenging or unsafe. This method uses a compass to roughly follow a GPS bearing in the field, enabling efficient navigation through wilderness areas with significant obstacles. By referencing new GPS bearings as frequently as needed on a "live" basis, the technique makes forward progress on an iterative basis while compensating for intentional lateral drift that renders the original bearing inaccurate. The introduction of live navigation to wilderness navigation is a significant advancement.
magnetic north	The direction in which the north-seeking end of a compass points in response to the earth's magnetic field. Compasses do not point to the magnetic poles but instead align with the local magnetic field, which eventually follows a curve that terminates at the magnetic poles. The measured declination of magnetic north varies over time with changes to the earth's internal geology.
map bearing	A map bearing is measured on a map using a protractor or a compass as a protractor. Map bearings, like GPS bearings, are unaffected by magnetic fields and are based on true north or grid north. This term differentiates it from a compass bearing and a GPS bearing.
markers	See waypoint.
meridian lines	See orienting lines.
Military Grid Reference System, MGRS	A coordinate system derivative of UTM and, for practical purposes, the same as USNG. For example, The Mountaineers Seattle Branch is at WGS84, 10T ET 55222 81579.
Mountaineers Ten	A guide published by The Mountaineers for assembling essential gear

Essentials™	for all backcountry trips.
navigation workflow	The steps required to prepare and coordinate a map, altimeter, compass, and GPS for wilderness navigation.
northing	A measure (like latitude) of the distance north, measured in meters, from the equator or South Pole. Northings are always positive numbers, always have seven digits (except just north of the equator), and are written without commas. In the Northern Hemisphere, northings are zero at the equator and increase northward. In the Southern Hemisphere, northings start at 10 000 000 at the equator and decrease southward. When combined with easting, it describes a location in the UTM system. There is no "southing." See easting, UTM.
orienting arrow	Marked arrow inside the compass housing, used 1) **On a map.** Aligning the compass with map north for measuring bearings on a map or plotting bearings onto a map, or 2) **In the field.** Aligning the magnetic needle with the orienting arrow allows for measuring or using bearings in the field. The orienting arrow on declination adjustable compasses can be rotated right or left independently of the rest of the housing to mitigate the effect of declination. Also known as the "declination arrow," "north arrow," or "north/south arrow." Known informally as "the shed."
orienting lines	Parallel lines in the housing of a compass. Aligning these (and hence the housing) with the north-south grid lines on a map and the compass base with the direction of travel allows the compass to function as a protractor to measure a compass bearing. Also known as *meridian lines.*
personal locator beacon (PLB)	An electronic device capable of sending a one-way distress message and the user's GPS-derived location to emergency first responders via government-based satellites. Similar to satellite communicators.
physical line of position	A (perhaps wiggly) linear feature in the landscape that can be identified on a map and observed directly. Examples include transits, ridges, rivers, shorelines, roads, trails, and power lines.
raster map	A static digital map format used in GPS applications. A digital map that is digitized by scanning a paper map. Contrast with vector map.

SATCOM	Satellite communications devices such as a satellite communicator, a PLB, or a satellite phone for communication from backcountry locations to first responders of others.
satellite communicator	An electronic device capable of sending (and, in some devices, receiving) communications through text messaging or email with an embedded GPS-derived location. Sent via commercial-based satellites, the communications can be casual messages to friends and family, or emergency messages to emergency first responders. Similar to a PLB. Also known as a “satellite messenger.”
sea level or geoid	The shape that the ocean surface would take if it were extended through the continents. It is a smooth but irregular surface whose shape results from the uneven distribution of the earth’s mass—also known as mean sea level. Geoid is similar to sea level and can be considered the same for wilderness navigation.
situational awareness	The navigator's active monitoring, anticipating, and comprehending crucial factors, including location, team dynamics, time, gear, and potential hazards like weather and terrain. Maintaining high situational awareness is imperative for making well-informed decisions regarding the route, adapting to unexpected changes, and guaranteeing the safety and success of a wilderness expedition.
solar noon	The time when the sun reaches its apparent highest point in the sky. This varies from noon due to position within a time zone, daylight savings time, and, to a lesser effect, the earth's elliptical orbit and tilt.
topographic map or topo	A map type that portrays the shape of the earth’s surface by using contour lines.
trail dead reckoning or TDR	Uses the formula **Rate X Time = Distance,** primarily to estimate expected hiking time or the distance hiked. Any two variables in this formula can be used to solve for the third. See Chapter 2, Trail Dead Reckoning, for explanation and examples. Contrast with “dead reckoning” and “live navigation.”
transit	The alignment of two visible landscape features with your location creates an accurate line of position. This is similar to the alignment of a rifle's front and back sights. A transit is useful when the features can be accurately identified on a map because your location lies somewhere along this LOP. This is similar but not to be confused with the astronomical use of the term where one celestial object aligns with another, such as when the moon aligns with the sun, generating a solar

	eclipse. Also known as a “range.”
triangulation or resection	A traditional high-visibility navigation technique that measures bearings to two or more widely spaced remote geographic features or physical objects and then plots them accurately on a map to calculate a position. The features or objects must be correctly identified and shown on the party’s map. Successfully measuring and then plotting two such bearings is typically impractical and considered obsolete. Using a single bearing and its intersection with another LOP, such as a trail, ridge, shoreline, or stream, can be practical and useful.
USNG	The United States National Grid (USNG) is the civilian version of MGRS and is used by parts of the US government and some search and rescue groups.
UTM	An acronym for Universal Transverse Mercator, one of the primary coordinate systems. Its grid is metric-based with easting and northing coordinates. A complete UTM coordinate comprises four components: datum, zone, easting, and northing. For example, when expressed as a UTM coordinate, The Mountaineers Seattle Branch’s location is WGS84, 10T 0555222E 5281579N.
vector map	A dynamic digital map format used in GPS applications, created in real-time from a database and dependent on the user's zoom level. It consists of elements like points, lines, polygons, labels, and symbols that are dynamically rendered for optimal resolution and readability. Vector maps provide sharp imagery at different zoom levels and small file sizes. Contrast with raster map.
waypoint	A set of coordinates that specify a position on (or above) the earth and is used for land navigation. Waypoints are natively stored in a GPS device as latitude and longitude coordinates in decimal degrees using WGS84. Waypoints may also contain elevation in meters, date and time in Coordinated Universal Time, and other parameters. A waypoint is sometimes called a “marker.”
zone	An area bounded by LOPs known as backstops that define an area. Such boundaries can define areas where the traveler is and is not. The “zone of uncertainty” is inside the boundaries, and the traveler knows they are somewhere in this zone. The “zone of exclusion” is outside the boundaries, and the traveler knows they are not there.

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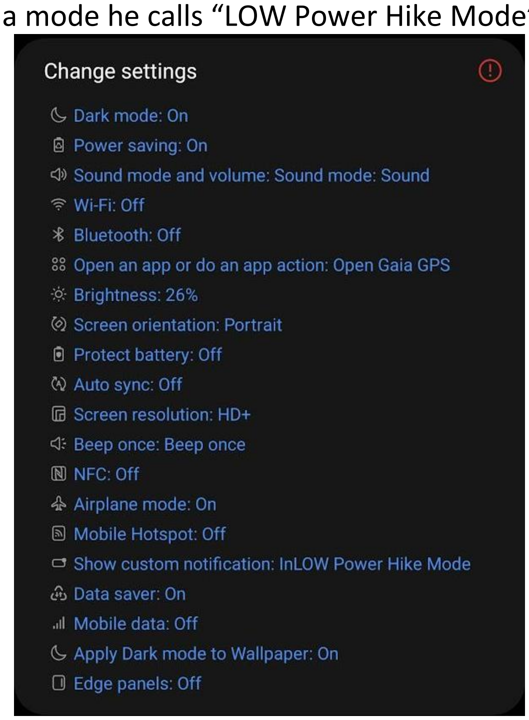
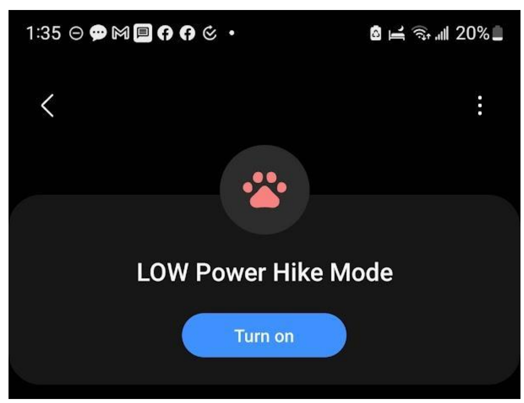
Appendix 1—
Phone and Other Electronics Power Saving Tips

1. **Screen Display:** Reduce brightness and refresh rate, use sleep mode, minimize use
2. **Low Power Mode:** Stops "most background app" processing
3. **Temp:** Keep warm, reduce battery drain
4. **Airplane Mode:**
   - Network communication off: Wi-Fi, Bluetooth, Cellular, Hotspot, application notifications
   - GPS remains on
5. **Manually close other applications:** Reboot your phone
6. **Location Services (GPS):** finds your location via GPS/Wi-Fi/hotspot/Cell Tower
   - Settings for each app: Never/While using the App/Always
   - Airplane Mode will turn off the network, but not GPS.
7. **Batteries degrade over time**, especially after two years
8. **Sturdy Power Bank** (e.g., GoalZero) + Rugged case.
9. ***Turn your phone OFF* and use your compass to follow a GPS Bearing.**
10. **Use the "Modes and Routines"** (android) to create a "Power Plan" to engage and disengage numerous settings to maximize power savings quickly. Apple/iOS phones have a similar function using an app called "Shortcuts," which allows you to automate tasks and create routines. Here are the settings the author uses on his Android phone in a mode he calls "LOW Power Hike Mode":





INSTRUCTOR RESOURCES

Annotated Glossary:

Instructors:

This text is my attempt to build on the integrated approach to navigation pioneered in Freedom 9 (2017). Reading any navigation text on the market feels out of sync with how we navigate today. For example, saying that a "map" is a piece of paper published by USGS feels woefully out-of-date. We all know that maps come in physical and digital forms. Each is important and has strengths and weaknesses that should be introduced to the student from the beginning. All current texts teach map and compass skills first and then, about two-thirds of the way through the book, say, "Oh, yeah, we also have GPS!" It is evident to me that we need a textbook that takes an integrated approach. This is the first textbook to integrate our traditional and digital tools to get the best of both.

Origins. I have been writing this draft textbook, "Modern Wilderness Navigation," since the beginning of 2020. It is entirely new, without a sentence from any other text, and contains over 100 new figures, tables, and insets.

New concepts. Writing about navigation in an integrated fashion required me to think deeply about basic concepts. What is a map? How do we measure and then use a bearing? What language is needed to describe the ways we can use these tools together? This annotated glossary is here to help instructors quickly understand new or changed terminology and new concepts.

Support. Beyond this text, please know I am available to answer student or instructor questions, conduct further discussions, or hold workshops to help bring these pages to life in your branch or organization. Since the publication of Freedom 9, the Seattle Navigation Committee has been reinventing all our classes and field trips to adopt this modern integrated approach. The resulting feedback from students and instructors has been overwhelmingly positive.

Open mind. I do encourage each of you to keep an open mind. Best practices for keeping us safe and on track have changed. I have attempted to describe these new best practices in this book, sometimes with new language or ideas. I invite you to participate. If something annoys you, or you have suggestions for different approaches or missing topics, please let me know!

Appreciation. Here, I would like to thank the folks who have given me 1000+ comments that have strengthened the current text considerably: John Godino (Mazamas), Travis Prescott (Foothills), Mike Kretzler (Olympia), Fritz Klein (Seattle Scrambling), Seattle Navigation Committee members: Dan Poor, Otto G, Jenny W, Stevie R., and my indispensable professional

outdoor magazine editor, Kristin S.

Tribute. Special thanks also go to Bob and Mike Burns, authors of the foundational work *Wilderness Navigation* in 1999. This text has served our community for a quarter century and paved the way for the innovations we explore today.

The table below outlines the key terms that are new or have been refined. This should be particularly useful for instructors, although students may also find it interesting.

The support for this project from the community has been GIGANTIC; for that, I am deeply grateful. I lost track of the number of user comments and suggestions for improvement at 1000, each representing a small or large improvement to the text. In turn, please get in touch with me with any questions or support I can lend to launching this new text in your branch or organization.

With sincere appreciation,

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NEW OR REFINED KEY TERMS, GROUPED	DEFINITIONS; *ANNOTATIONS IN ITALIC*
CORE PRINCIPLES	*These are some of the core principles established in Freedom 9.*
• **five tools of navigation**	The five core tools considered essential for wilderness backcountry navigation are 1) physical maps, 2) digital maps on GPS device, 3) altimeter, 4) compass, and 5) SATCOM. *In the 6th decade since the launch of GPS, practitioners focus more on the "digital map" than the "GPS device." This slight change in order shifts the focus more toward maps generally, and digital maps rather than GPS devices.*
• **situational awareness**	The navigator's active monitoring, anticipating, and comprehending crucial factors, including location, team dynamics, time, gear, and potential hazards like weather and terrain. Maintaining high situational awareness is imperative for making well-informed decisions regarding the route, adapting to unexpected changes, and guaranteeing the safety

	and success of a wilderness expedition.
line of position (LOP)	A physical LOP or an instrument LOP. The intersection of two or more LOPs is used to determine location. (Also known as a position line or reference line.) See physical line of position and instrument line of position. *Since it has never been described in depth, the critical question for this text has been, "<u>What language is needed to describe the ways we can use these tools together?</u>" I have partially answered this tricky question by resurfacing an old navigation term and stretching it a bit:* ***line of position or LOP****.* *Think of a LOP not as a new idea but as a higher-level term for the many ways we can find our location or a direction to travel. Line of position is an old navigation term that has nautical origins. It is also used in the NOLS navigation book and others.* *We can establish our position with two LOPs that run under our feet. "Triangulation" using two or more compass bearings is an often taught but rarely used example. This text attempts to encourage the learner to look for physical LOPs in the landscape and measure instrument LOPs with GPS, altimeter, or compass. With LOPs, we can establish location, define a LOP to follow (handrail), and understand the limits of the handrail or zone.* *I hope you will find the concept of "line of position" useful for teaching and that our students will find it helpful for learning. I hope the continual search for LOPs will bring creativity to how they are combined for navigation and increase situational awareness. I would also maintain that if you are not following a LOP or at least in a zone bounded by LOPs, you are not navigating.*
• **physical line of position**	A (perhaps wiggly) linear feature in the landscape that can be identified on a map and observed directly. Examples include transits, ridges, rivers, shorelines, roads, trails, and power lines.
• **instrument line of position**	An instrument line of position (LOP) is a LOP that requires an instrument to measure. Instrument LOPs are elevations, compass bearings, or coordinates measured by an altimeter, a compass, or a GPS.

• **handrail**	A handrail is a LOP that can be used to guide travel by sight (physical LOP) or instrument (instrument LOP)
• **backstop**	A LOP that runs crosswise to the direction of travel that alerts of a turn or destination. Also known as a "catch line," "catching feature," or "baseline."
• **transit**	The alignment of two visible landscape features with your location creates an accurate line of position. This is similar to the alignment of a rifle's front and back sights. A transit is useful when the features can be accurately identified on a map because your location lies somewhere along this LOP. This is similar but not to be confused with the astronomical use of the term where one celestial object aligns with another, such as when the moon aligns with the sun, generating a solar eclipse. Also known as a "range."
• **zone**	An area bounded by LOPs known as backstops that define an area. Such boundaries can define areas where the traveler is and is not. The "zone of uncertainty" is inside the boundaries, and the traveler knows they are somewhere in this zone. The "zone of exclusion" is outside the boundaries, and the traveler knows they are not there.
bearing	A direction from one location to another measured in degrees from true north. Also known as a "true bearing." A bearing is measured on a map (map bearing), measured in the field using a compass (compass bearing), or with a GPS (GPS bearing). The US army (but not the US Navy or the armies of other English-speaking nations) uses the alternative term "azimuth." See also compass bearing, map bearing, and GPS bearing. *The lowly bearing also needed a re-think. When all we had was a map and compass, there were only three combinations of how we measured and then used bearings: map to compass, compass to map, and compass to compass. (We never seem to measure a map bearing and then use it on a map.) Adding the GPS for measuring and using bearings increased these pairings from three to eight. I believe this requires us to be crisper in our language to differentiate between GPS bearings, map bearings, and compass bearings. To "keep my bearings" and allow me to write clearly about these eight pairings, I needed to create Figure 3-11 above. I hope you and our students will also find this approach helpful.* *In addition, the text emphasizes a core concept that many of our classes (at least in Seattle) have often missed in the past: "Measuring and then using bearings are the two halves of a single process whose purpose is to find our location or guide our next step"*

(see page 44). Otto G., our Seattle Navigation Co-Chair, has highlighted this in his Introduction to Map and Compass class.

• **GPS bearing**	A bearing derived using a GPS device which includes both bearing and distance toward an objective. This new term differentiates it from a compass bearing or a map bearing.
• **map bearing**	A map bearing is measured on a map using a protractor or a compass as a protractor. Map bearings, like GPS bearings, are unaffected by magnetic fields and are based on true north or grid north. This term differentiates it from a compass bearing and a GPS bearing.
• **compass bearing**	Is measured using a compass in the field. This term differentiates it from a map bearing and a GPS bearing.
GPS	GPS is an acronym for the Global Positioning System of the US Air Force. In everyday use and this book, GPS refers to a GPS device, the various GNSS collectively, or something that uses these systems (e.g., GPS navigation, GPS bearing). *The term "GPS" has evolved to include all of the world's GNSS systems, the devices we use to measure GPS signals and an adjective.*
GNSS	GNSS (Global Navigation Satellite System) is the generic name for any global satellite-based navigation system. These systems include the US Global Positioning System (GPS), the Russian GLONASS system, the European Galileo system, and the Chinese BeiDou system. (See GPS). *While "GNSS" is a good academic term, it is not on the tip of anybody's tongue. I do not use the term except in the introduction to GPS.*
• **GPS device**	A GPS device is an instrument that can determine a location based on signals from GPS satellites. Its form is typically a phone, a specialized device, or a watch. *The term "GPS" has evolved to include all of the world's GNSS systems, the devices we use to measure GPS signals and an adjective.*
• **GPS receiver**	An out-of-date term for a GPS device, used before such devices were integrated with digital maps. *This term has become obsolete from an era when "GPSs" were $500*

clunky devices. Today, the term is no longer used, and a phone is the overwhelming form factor for a GPS device. While these devices, now known as "dedicated GPS devices," *are a sliver of the market, they have evolved to have new functionality (especially satellite communications) and are still needed in harsh conditions.*

- **dedicated GPS device** — A specialized handheld device designed for navigation purposes. These rugged devices excel in harsh environments, offering easy operation, even in the rain or while wearing gloves. These devices can incorporate two-way satellite texting, transforming them into tools that combine GPS, digital maps, digital compass, altimeter, and satellite communicators, covering the essential navigation tools.

  Note that these devices occupy a small shelf at REI and can legitimately be called "Garmins" since Garmin is the last remaining manufacturer.

- **GPS app** — A phone or tablet app that combines digital maps with a device's GPS, compass, and altimeter capabilities to assist navigation. This combination is referred to as "GPS," constituting one of the five tools of navigation.

NAVIGATION METHODS

Each of these five navigation methods numbered below has its place, but they are not equal in importance to our students:

1. *In my backcountry off-trail wanderings, "live navigation" or "following a GPS bearing" is a breakthrough technique that keeps my situational awareness high.*
2. *Trail dead reckoning, a super-useful technique for trail hikers, typically has no name or is mislabeled as "dead reckoning." The term is not new but not common.*
3. *The Direction-of-slope method is an intriguing technique that works in low-visibility conditions without needing electronics. We are now teaching this in Seattle.*
4. *I believe we need to relegate "dead reckoning" to that of a valid backup technique, not a primary one.*
5. *"Triangulation" is an often-taught but almost never-used technique. I struggled with what to do with this technique for many years. I finally realized that it is just a specific example of the MANY ways we can use LOPs together to determine location. Occasionally, we could use a single compass bearing with another LOP, but the conditions*

necessary to use two or more bearings are rare.

1. **live navigation; follow a GPS bearing**	An emerging form of navigation that leverages real-time data to guide travelers to their destinations, primarily known to the public through such apps as Google Maps and Waze. In wilderness navigation, we "follow a GPS bearing" as a primary off-trail technique when straight-line travel is challenging or unsafe. This method uses a compass to roughly follow a GPS bearing in the field, enabling efficient navigation through wilderness areas with significant obstacles. By referencing new GPS bearings as frequently as needed on a "live" basis, the technique makes forward progress on an iterative basis while compensating for intentional lateral drift that renders the original bearing inaccurate. The introduction of live navigation to wilderness navigation is a significant advancement.
2. **trail dead reckoning or TDR**	Uses the formula **Rate X Time = Distance,** primarily to estimate expected hiking time or the distance hiked. Any two variables in this formula can be used to solve for the third. See Chapter 2, Trail Dead Reckoning, for explanation and examples. Contrast with "dead reckoning" and "live navigation."
3. **direction-of-slope method**	Method to determine location (or several possible locations) using only a topographic map, an altimeter, and a compass, even in zero visibility. Also known as the "contour-tangent method."
4. **dead reckoning**	A backup off-trail navigational technique that closely follows a map bearing as the line of position in a straight line from one known location to another without reference to visible landmarks, celestial bodies, or GPS. This originally nautical method is often challenging for land navigation where terrain can make straight-line travel difficult or dangerous. Compare with trail dead reckoning and live navigation.
5. **triangulation or resection**	A traditional high-visibility navigation technique that measures bearings to two or more widely spaced remote geographic features or physical objects and then plots them accurately on a map to calculate a position. The features or objects must be correctly identified and shown on the party's map. Successfully measuring and then plotting two such bearings is typically impractical and considered obsolete. Using a single bearing and its intersection with another LOP, such as a trail, ridge, shoreline, or stream, can be practical and useful.

digital map	A map is displayed on the screen of an electronic device, which is typically GPS-enabled, such as a dedicated GPS device or a phone or tablet with a GPS app. Digital maps come in two primary forms: raster and vector digital maps. *This may seem a bit technical, but how do we choose among the 1000+ maps available on Gaia? Students who do not understand the difference between these two map types will often be surprised by the map's different behavior in zooming and downloading.*
• **raster map**	A static digital map format used in GPS applications. A digital map that is digitized by scanning a paper map. Contrast with vector map.
• **vector map**	A dynamic digital map format used in GPS applications, created in real-time from a database and dependent on the user's zoom level. It consists of elements like points, lines, polygons, labels, and symbols that are dynamically rendered for optimal resolution and readability. Vector maps provide sharp imagery at different zoom levels and small file sizes. Contrast with raster map.

