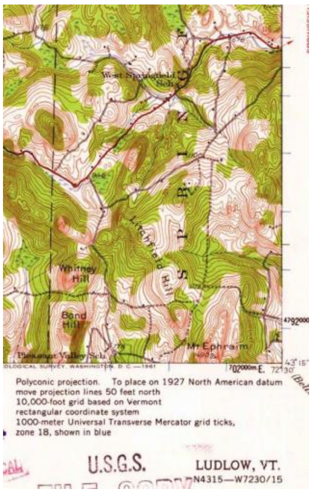
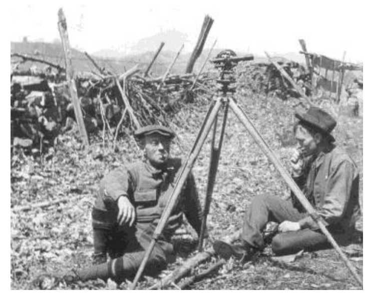
# Finding Stellafane: Early 20th Century Surveying Methods as Used by the U.S. Geological Survey and Russell W. Porter





George Springston,
Research Assistant Professor, Dept. Earth & Environmental Sciences, Norwich University and Springfield Telescope Makers

February 5, 2022

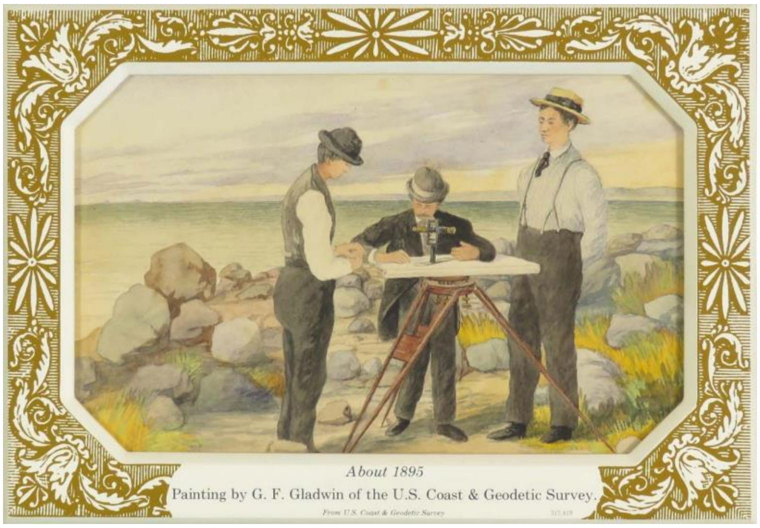
Introduction
The need for topographic maps

Early mapping techniques used by Porter and USGS
- Triangulation
- Astronomical Observations
- Leveling
- Plane Table Mapping
- Map Production

Russell Porter as an exploration surveyor and mapmaker:
The Cook expedition to Denali and the Fiala-Ziegler North Pole attempt

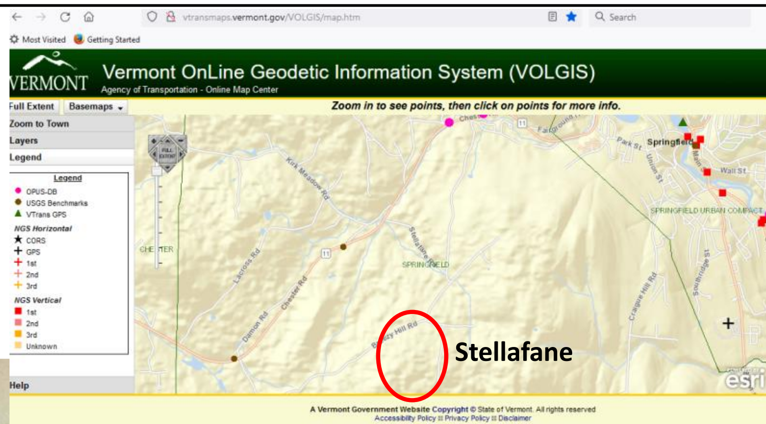
The coming of aerial mapping methods.

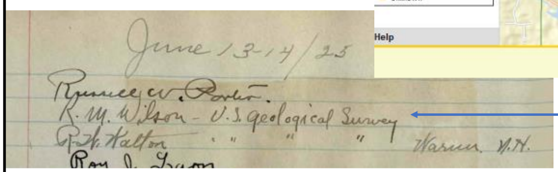
Present-day revolutions in mapping




**Plane Table Mapping**
https://americanhistory.si.edu/collections/search/object/nmah_1820979

My background: Academic background in geology, worked as a land surveyor, lifelong interest in maps.

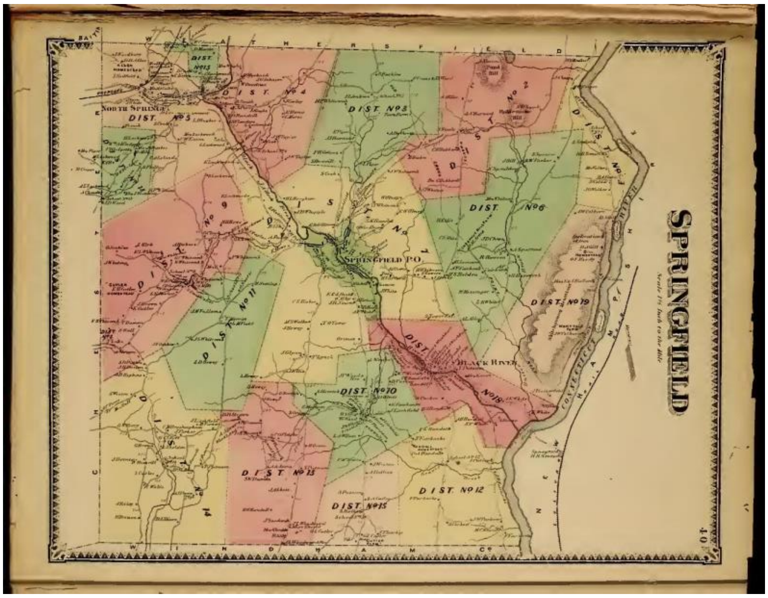




Wilson signature in club minutes

**The Mystery of the Benchmark at the Clubhouse**

Clearly an “official” one, but missing from the topo maps and the official database. Almost certainly placed by USGS surveyor R.M. Wilson in 1925 for the topographic mapping in the area. More on that later.

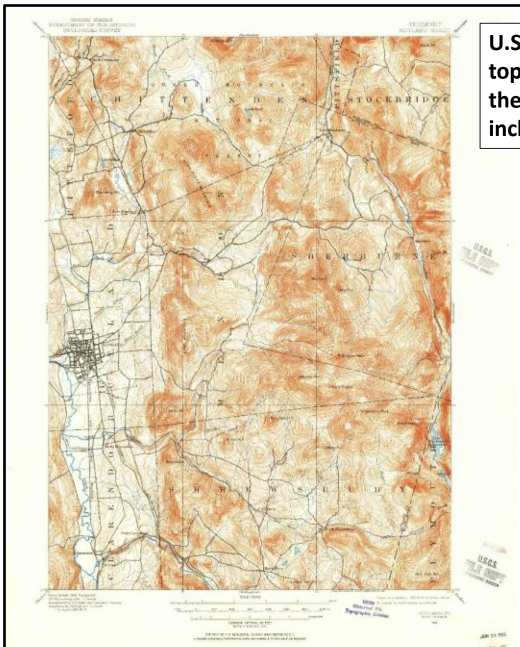
The story of the surveyor’s visit is told in Willard (1976).



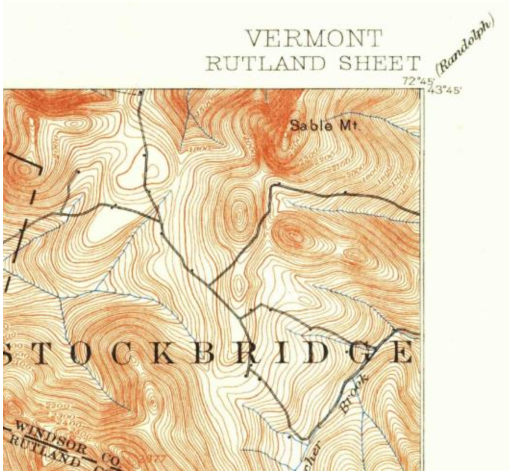

**1869 map of Springfield from Beers' Atlas of Windsor County, Vermont**

Maps like this were fine for showing the roads and often the locations of individual buildings, but were woefully inadequate for detailed planning, engineering, and geologic studies.

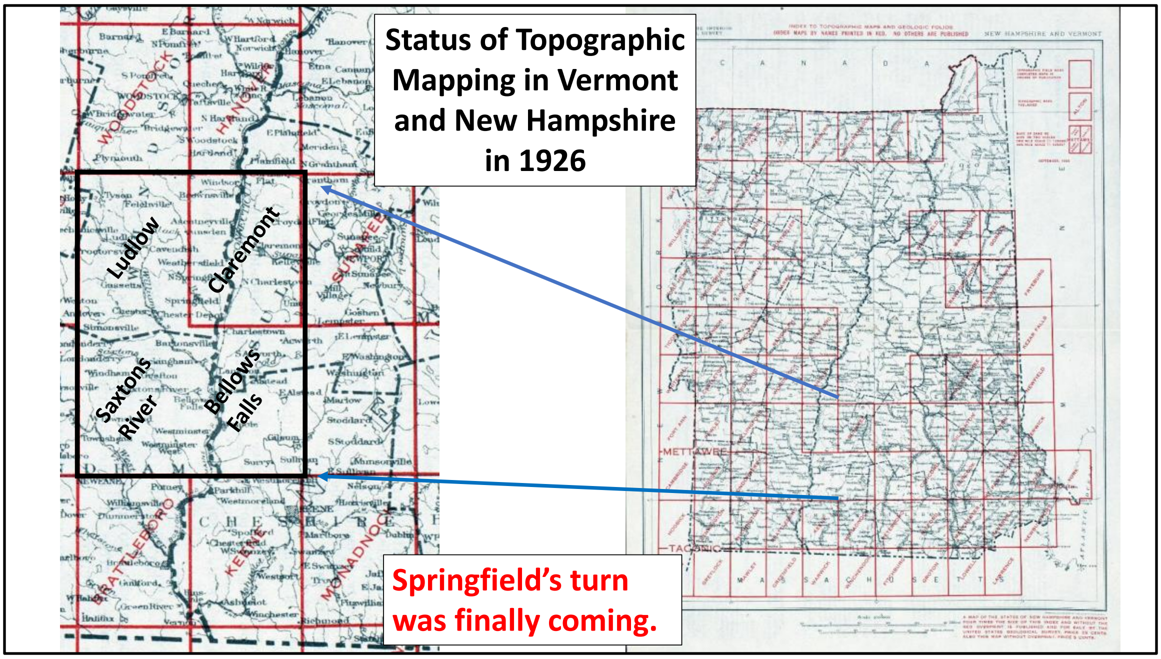
Not much use for a hunter or hiker either.



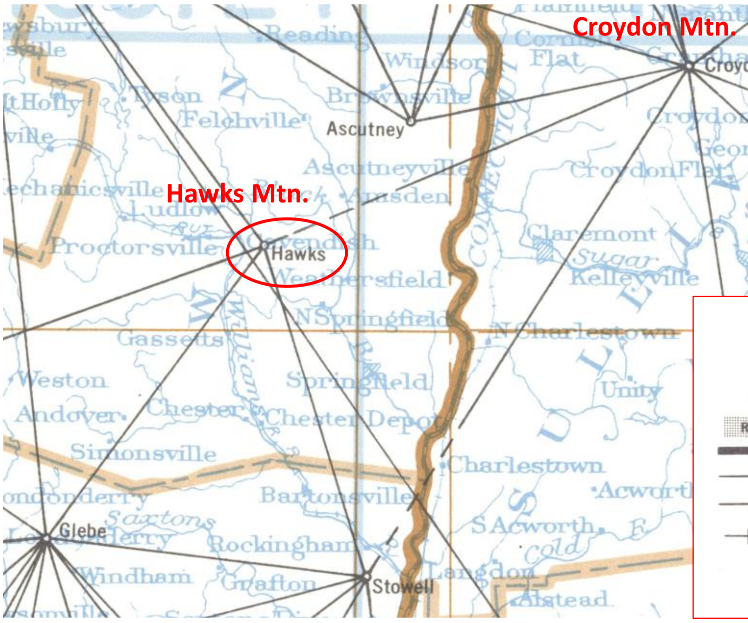
**U.S. Geological Survey to the rescue! The 1891 Rutland 1:62,500 topographic sheet was one of the first of a series that would, by the 1940s, provide complete coverage of Vermont at about one inch to the mile (1:62,500).**




These early topos had all the features we've come to expect: Contours, water bodies, roads, town boundaries, etc.



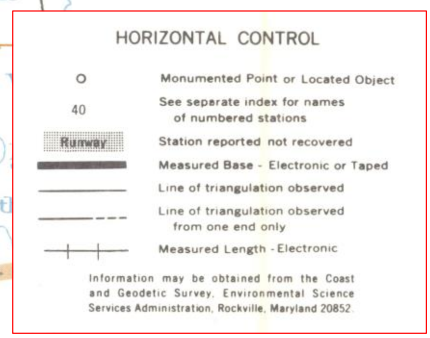

By the late 1920s, most of Vermont was covered, with the exception of the north-central and eastern parts.



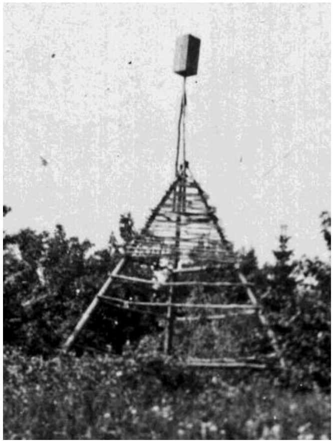

# Triangulation to Establish Control Points: The First Step

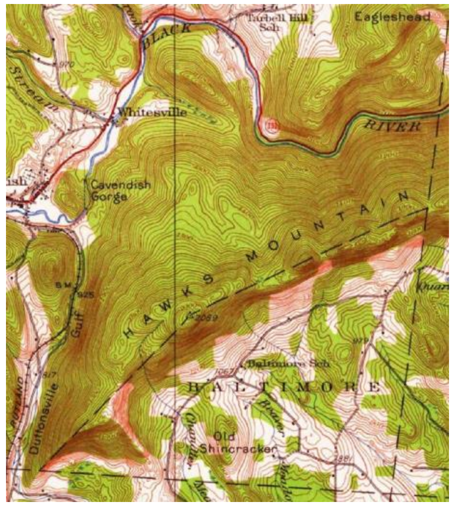
Coast and Geodetic Survey Triangulation Network Near Hawks Mountain.





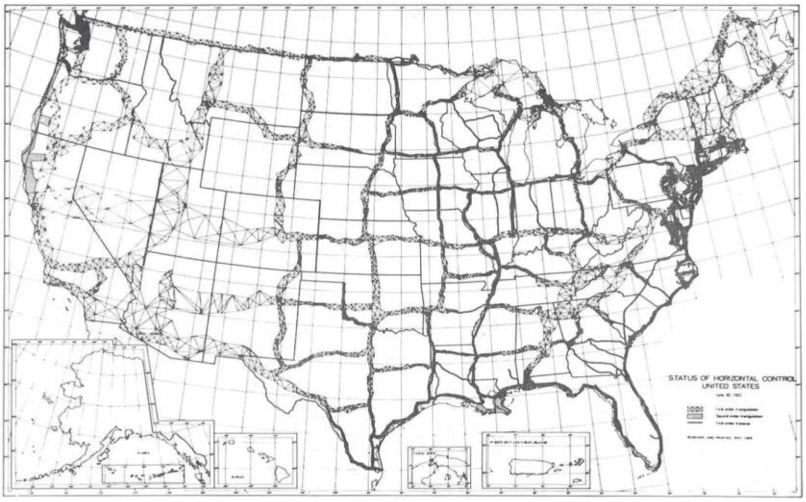

The idea of triangulation is that if you measure the length of one side of a triangle and at least two of the angles, then the lengths of the other sides can be calculated. The station on Hawkes Mountain, N of Springfield was located from Croydon Mountain in 1875. For such widely separated points it was possible to measure the angles very accurately, but distances were difficult to measure.





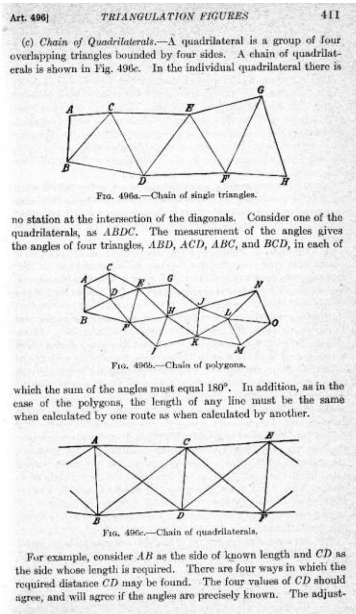

**Left and Right: Porter led the Telescope Makers up Hawks Mountain in 1921 to erect a tower over the old survey station from 1875. The Telescope Makers placed a plaque at the site one year later. Center: Closeup of 1929 Ludlow sheet.** **Photos stm0118 and stm0453, STM Photo Archive.**

Porter wanted to know the position of Springfield more precisely. At his instigation the group undertook a laborious outing: building a signal tower. The story of U.S.G.S. surveyor Robert Wilson's subsequent visit to Hawks Mountain and Stellafane in 1925 is told in Willard (1976).




**U.S. Triangulation Network as of 1931. The first transcontinental line of triangulation (along the 39th parallel) was completed in 1896.**
https://gisgeography.com/wpcontent/uploads/2016/05/Horizontal_Control Network_of_the_United_States_June_1931.jpg

In the 1920s the Hawks Mtn station was part of a growing network of precisely located stations that extended across the U.S.



Art. 496] *TRIANGULATION FIGURES* 411

(c) *Chain of Quadrilaterals.*—A quadrilateral is a group of four overlapping triangles bounded by four sides. A chain of quadrilaterals is shown in Fig. 496c. In the individual quadrilateral there is

Fig. 496a.—Chain of single triangles.

no station at the intersection of the diagonals. Consider one of the quadrilaterals, as *ABDC*. The measurement of the angles gives the angles of four triangles, *ABD*, *ACD*, *ABC*, and *BCD*, in each of

Fig. 496b.—Chain of polygons.

which the sum of the angles must equal 180°. In addition, as in the case of the polygons, the length of any line must be the same when calculated by one route as when calculated by another.

Fig. 496c.—Chain of quadrilaterals.

For example, consider *AB* as the side of known length and *CD* as the side whose length is required. There are four ways in which the required distance *CD* may be found. The four values of *CD* should agree, and will agree if the angles are precisely known. The adjust-

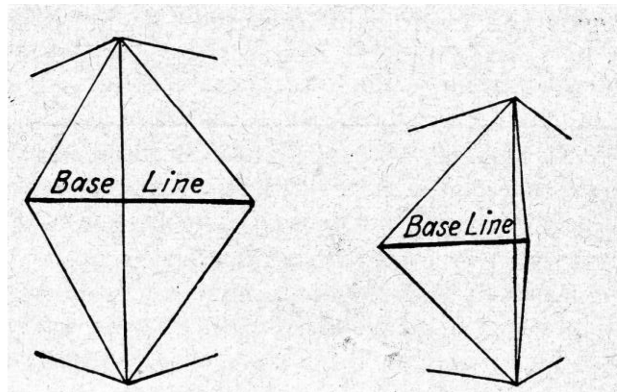



Fig. 498.—Base nets.

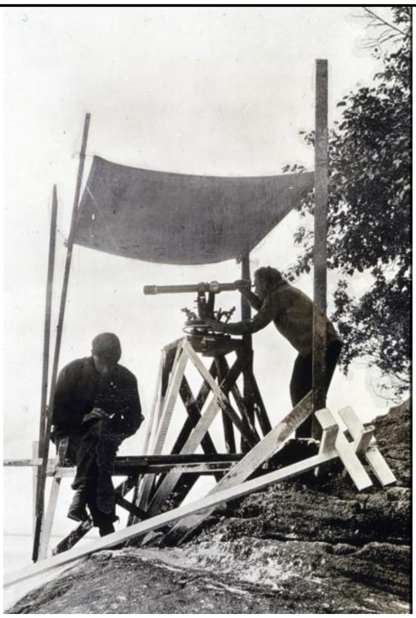
Triangulation arrangements and base lines. A measured base line was needed once in every 10 or 15 triangles. These were always located on flat (usually low) ground.
From Davis, Foote, and Raynor, 1940.

Chains of quadrilaterals allowed multiple ways to calculate each side.

Baselines were measured with incredible care. Accuracy of the best ones was ~ 1 part per million. The man on the left is using a spring balance to provide a precise amount of tension to the invar tape. The man on the right is carefully scribing a mark on the post.

From: https://photolib.noaa.gov/Collections/Coast-Geodetic-Survey/Geodesy/Triangulation/

Baselines were measured in an “inchworm” fashion, one tape-length at a time. A baseline used in the U.S. Coast and Geodetic Survey triangulation might be miles long and might take days to measure. Porter would have used much shorter ones in his exploration work: Perhaps a few hundred yards.



Instrumentation: Porter and the USGS measured the angles with precision theodolites. For the highest class of work the sum of the angles of each triangle had to close within one second. On the right is a Parkhurst theodolite capable of measuring directly to one second.

From:
https://photolib.noaa.gov/Collections/Coast-Geodetic-Survey/Geodesy/

## Signals

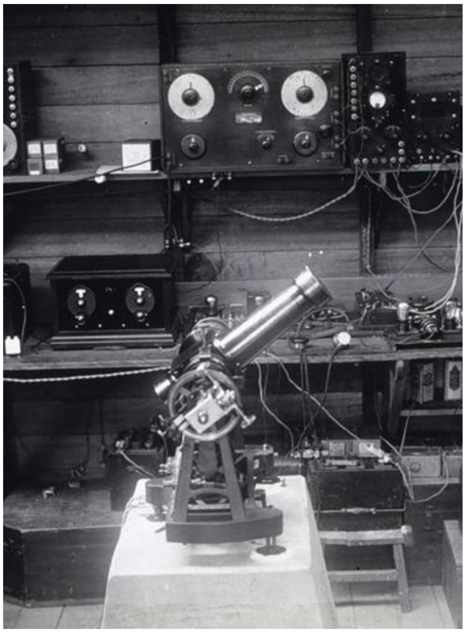
Triangulation stations had to be visible from miles away. The Hawks Mountain signal erected by Porter was typical of those used in remote areas. Precision surveys in the 1920s often used heliostats which could be seen over long distances on a sunny day.

Left: Plane table mapping below a signal flag. From USGS photo library.

Right: Signaling with a heliostat in 1922.

https://photolib.noaa.gov/Collections/Coast-Geodetic-Survey/Geodesy/Triangulation/

In the 1920s triangulation was increasingly being done at night with bright electric lamps as signals.



## Astronomical Observations in the 1920s

Triangulation yielded relative positions of stations, but astronomical observations were needed at some of the stations to provide absolute positions.

**Azimuths** of triangulation lines were determined by Polaris observations with theodolites using 12 or more sets of observations (direct and inverted). Final accuracy ~ 0.3 arcsecond.

**Longitude** was still usually found by telegraphic comparison of stations using astronomical transit. Simultaneous transit times for 5 or 6 stars were observed for each of 3 nights. Final accuracy ~ 0.3 seconds of longitude. Radio was then coming into use for this purpose.

**Latitude**, using an astronomical transit or zenith telescope to measure relative angular distances of meridian transits of pairs of stars on either side of the zenith. Much more accurate than Polaris and solar observations. With observations on 12 pairs of stars, final accuracy within 0.1 second of latitude.

Photo: astronomical transit and radio gear, 1926. From: https://photolib.noaa.gov/Collections/Coast-Geodetic-Survey/Geodesy/Astronomic-Latitude-and-Longitude/ , downloaded 1/13/2022.

Radio was in use for longitude determinations by 1922. USNO broadcasts from Annapolis and Arlington.

**Accuracy of Methods**:
It took special equipment and techniques to determine latitude and longitude with high accuracy. A normal surveyor's transit such as my Buff & Buff, could only be used to determine latitude to within about one minute.

At Stellafane:
One minute of latitude = 6073 feet = 1851 meters
One second of latitude = 101.2 feet
One minute of longitude = 4437 feet = 1352.5 meters
One second of longitude = 73.9 feet

NCAT Coordinate Conversion calculator:
https://www.ngs.noaa.gov/NCAT/
One degree of latitude (or one degree of longitude at the equator) = 60 nautical miles*
One Nautical Mile = 6076.12 feet = 1852.02 meters

A typical early 20$^{th}$ century transit. My Buff & Buff transit with horizontal and vertical scales reading to one minute on the verniers.

## Elevations Also Needed:

**Triangulation could give fairly accurate elevations. However, most precise work was by**

## Differential Leveling.

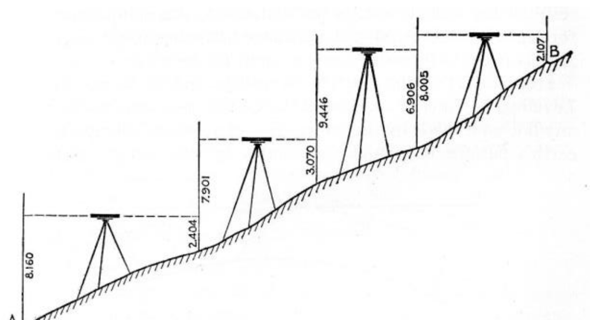



FIG. 43. DIAGRAM ILLUSTRATING DIFFERENTIAL LEVELING.

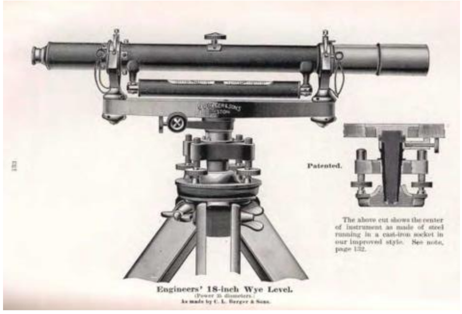
**GRADES OF WORK**

The permissible limits of error in the three grades of work required in leveling are indicated below.

| | | |
|---|---|---|
| First order | feet | 0. 017 √length of section in miles |
| | millimeters | 4 √length of section in kilometers |
| Second order | feet | 0. 035 √length of section in miles |
| | millimeters | 8. 4 √length of section in kilometers |
| Third order | feet | 0. 05 √length of circuit in miles |

Differential leveling transfers elevations from one point to another step-by step using a level and rod. The method could be highly accurate: For First Order levelling, the closure on a 10 km loop had to be within 13 mm.

## Typical Surveyor's Level




Berger and Sons Catalog, 1900.

**CLAREMONT QUADRANGLE** [13a]

[Latitude 43°15′–43°30′; longitude 72°15′–72°30′]

**WINDSOR COUNTY**

**From Connecticut River northwest along State highway to Springfield, thence north along roads to Brownsville, thence east and north to Windsor (by E. L. McNair in 1925)**

| | |
|---|---|
| Cheshire Toll Bridge (steel-truss bridge on Charleston-Springfield highway over Connecticut River), at N. end of, at S. end of W. concrete wall; chiseled square (by R. F. Olds, Bellows Falls, Vt., July 1928) | 321. 53 |
| Cheshire Toll Bridge, 1.0 mi. NW. of, 125 ft. N. of N. end of steel bridge over Black River, 20 ft. N. of rd., on large boulder; chisel cut | 301. 19 |
| Cheshire Toll Bridge, 1.6 mi. NW. of, 2.8 mi. SE. of Springfield, 0.2 mi. E. of bridge over Black River, at junction of rd. N., 25 ft. N. of rd., on large boulder; standard tablet stamped "Mac No 82 1925" | 316. 588 |
| Springfield, 1.8 mi. SE. of, 20 ft. S. of rd., on top of concrete water tank; chiseled square | 339. 82 |
| Springfield, 0.7 mi. E. of, almost opposite W. end of Jones & Lamson machine shop, 20 ft. S. of rd., on boulder; chiseled square | 337. 70 |
| Springfield, on N. side of Main Street, at entrance to Savings Bank building, at E. end of step; standard tablet stamped "Mac No 83 1925" | 409. 832 |
| Springfield, 0.7 mi. N. of, at NW. corner of large concrete rd. culvert; chiseled square | 567. 90 |
| Springfield, 1.8 mi. N. of, 700 ft. N. of rd. forks, 20 ft. W. of rd., on boulder; chiseled square | 728. 94 |
| Springfield, 2.7 mi. N. of, 3.3 mi. S. of Weathersfield Center, about 800 ft. N. of rd. forks, at white house on top of hill, 50 ft. W. of rd., 6 ft. N. of stone wall, in pasture, on large boulder; standard tablet stamped "Mac No 84 1925" | 991. 333 |

USGS Bulletin 888, Spirit Leveling in Vermont, 1896-1935, 1938.

The USGS ran several hundred miles of leveling in support of topo mapping in Vermont in the 1920s.

## Plane Table Mapping

**Porter and the USGS topographers did the actual topographic mapping using plane tables.**

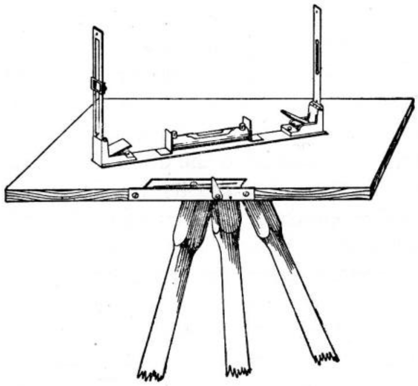


FIG. 97b.

https://www.usgs.gov/media/images/cartographers-field

**Cartographers in the Field**
Hal Shelton, 1940

The alidade in the topographer's left hand is a sighting instrument used to determine distance and elevation of points. The topographer then sketched features and contour lines, drawing a paper map on the plane table in real time.

It took an artist's eye to quickly represent the landscape as a contour map.

"This 4 ft. x 6 ft. painting is on display in the USGS library in Menlo Park, California."

From https://www.usgs.gov/media/images/cartographers-field

## Locating Features With Plane Table

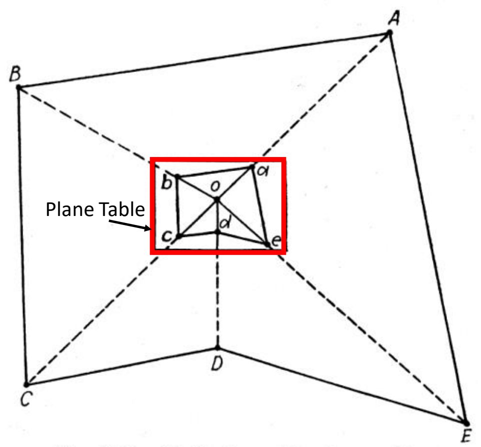



Fig. 343.—Radiation with plane table.

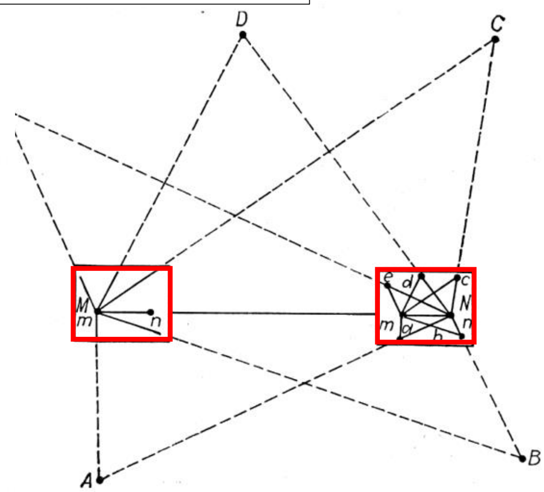



Fig. 345.—Intersection with plane table.

From Davis and Foote, *Surveying: Theory and Practice*: McGraw-Hill, 1032 p.

Porter would have done a lot of intersection in his work, sighting on distant peaks from valley locations and occasional prominences.

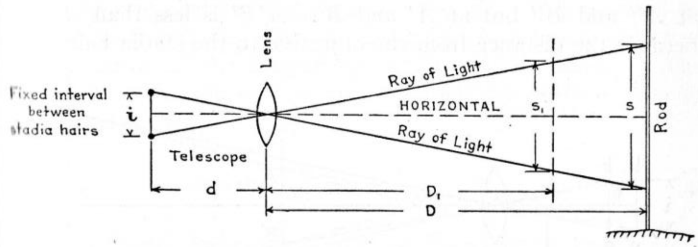
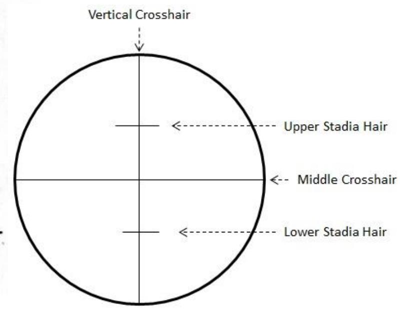



FIG. 92a. DIAGRAMMATIC REPRESENTATION OF PRINCIPLE OF THE STADIA.



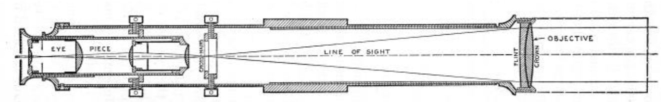




FIG. 14. LONGITUDINAL SECTION OF AN EXTERNAL FOCUSING TRANSIT TELESCOPE (ERECTING EYEPIECE). Light rays meet at Cross-hairs; in Eyepiece they become inverted and again erected before reaching the eye.

**Above: Stadia hairs on reticle in telescope. With a stadia ratio of 1:100, if 1.01 feet is visible between the stadia hairs, the rod is 101 feet from the instrument.**

**Distance measurement using the stadia method**

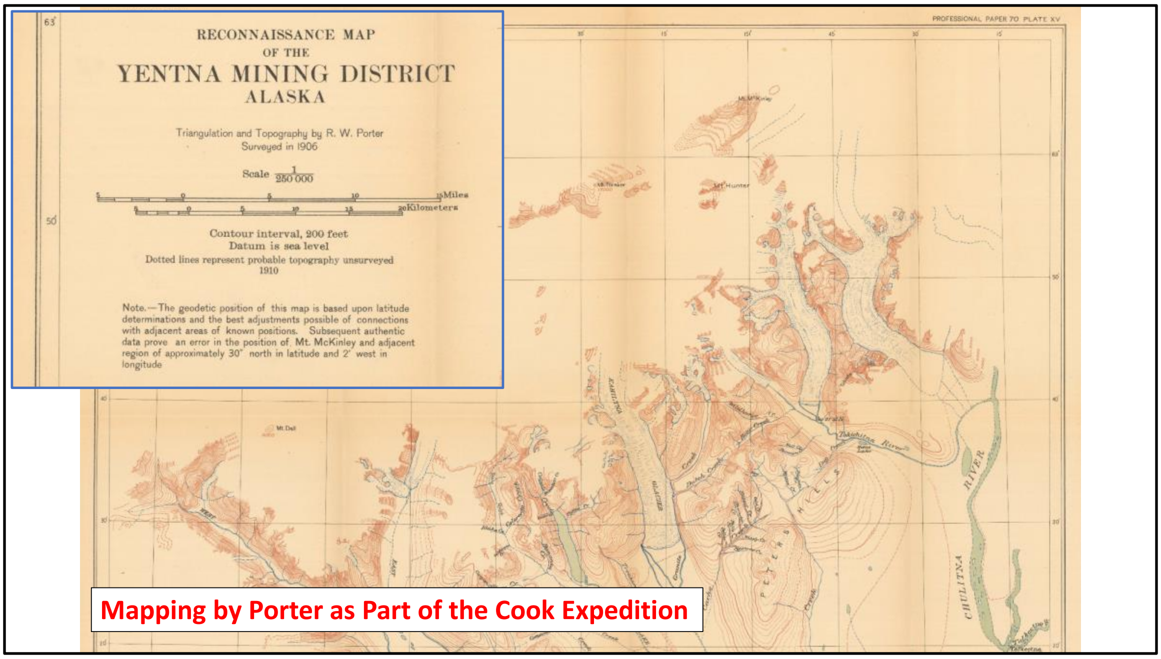
The stadia method was extensively used for topographic mapping. It was quick and reasonably accurate for distances up to around 500 feet.

## The Frederick Cook Expedition to Denali in 1906

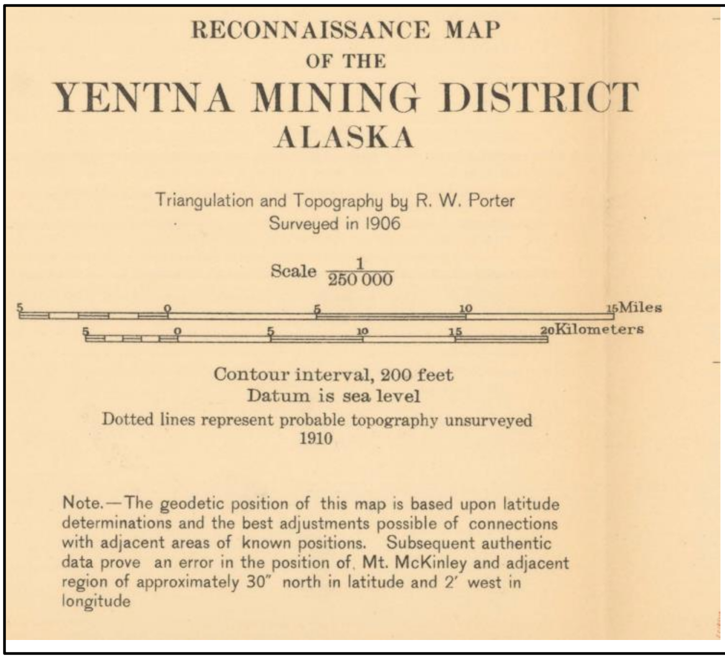
PORTER SKETCHING CONTOURS FROM ABOVE THE CLOUDS

**In late May of 1906 Frederick Cook set out into the Alaska wilderness to explore the Denali region of Alaska. Porter was the expedition's cartographer.**

From Cook, F.A., 1909, To the Top of the Continent: Hodder & Stoughton, London, 321 p.




**Mapping by Porter as Part of the Cook Expedition**




**Porter's Map of the Yentna Mining District: A Classic Example of Exploration Surveying: Extreme terrain, limited time, simple instruments, and ultimately, limited accuracy (see note at bottom of title block)**

**Equipment: Small theodolite with verniers reading to 1 minute of arc, small plane table and open-sight alidade, aneroid barometer, hand level, steel tape, compass and, (importantly) three Waltham chronometers.**

**How Porter Determined Accurate Position of a Survey Station:**

**Latitude by solar and star observations to better than 1 minute.**
**Elevation by direct leveling, trigonometric calculations, and aneroid barometer readings.**
**Azimuth by compass and Polaris observations.**
**Longitude was the tough one. Porter had no telegraph or radio time signals. He was totally dependent on the chronometers. The best he could do was to document the chronometer error rate by making repeated theodolite observations of sun and stars at fixed stations to document changes in apparent time.**

> “Time was kept by three Waltham chronometer watches, rated by solar observations at intervals of about a week throughout the season. They were compared daily. Watch No. 4 was put out of service June 25 and No. 14 On August 24, both from being submerged in water. No. 15, used for recording, was set to approximate Greenwich mean time and ran continuously. The errors of this watch (No. 15) on local and Greenwich mean time and its daily rate for the season were as follows….”

**The final error on the one watch that ran continuously from May 29 to September 27, 1906 totaled 9 minutes, 27 seconds, with the rate (observed at fixed stations) ranging from minus 10.9 seconds to plus 12.7 seconds per day.**

**Fiala-Ziegler Polar Expedition of 1903-5**
**Wintering at Teplitz Bay, Franz Josef Land, Arctic Ocean (part of Russia today)**

Porter's methods were similar to those of the Denali expedition, but a fine Repsold altazimuth instrument was available for base operations. This could be read to 4 seconds of arc on the verniers. Latitudes were determined by meridian transits of stars. By undertaking many brutally challenging winter observing sessions, Porter was able to determine longitude by lunar culminations and occultations of stars to within several seconds. Sometimes it was so cold that the kerosene in their lamp solidified. See Bert Willard's book for details.

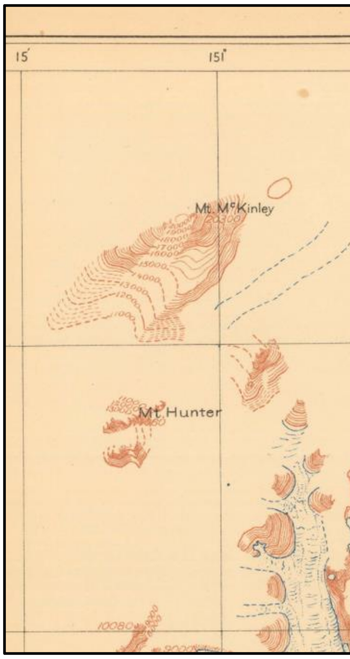
Not to mention that the ship was crushed in the ice and it was over a year before they were rescued!

**Porter's interest in surveying and mapping continued long after the expeditions ended. Here's Porter (left) and a companion with a surveying instrument. Springfield area? Early 1920s? See next slide for closeups.**

**Photo stm0118 from STM Photo Archive.**


**What instrument is this? I believe this is one of the two Berger theodolites with 4-inch circles described in the report of the Fiala Ziegler Polar Expedition (Porter used one of these on the Alaska expedition). See the stencil on the tripod leg.** Photo stm0118 from STM Photo Archive.

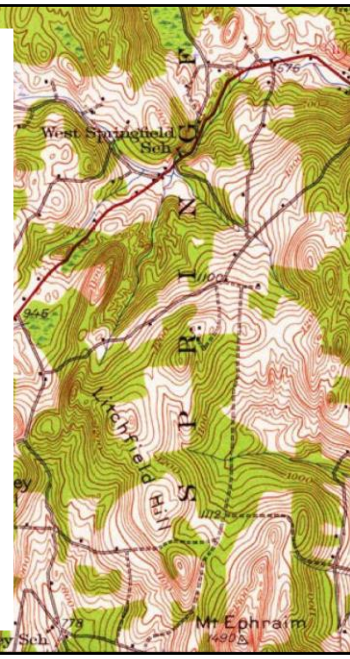
What ever became of this instrument? A custom instrument like this would have been greatly valued by anyone interested in surveying and mapmaking. If Porter had this in the 1920s, it would seem likely that he would have taken it to California with him.

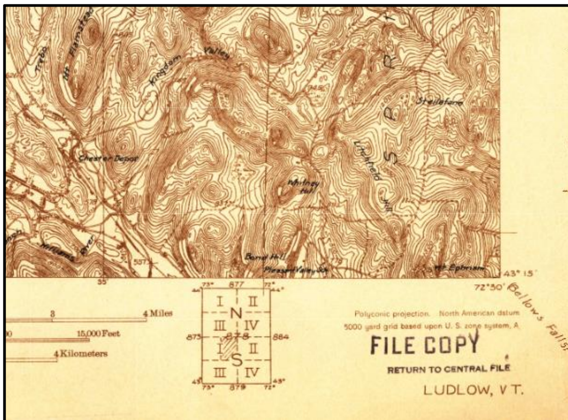


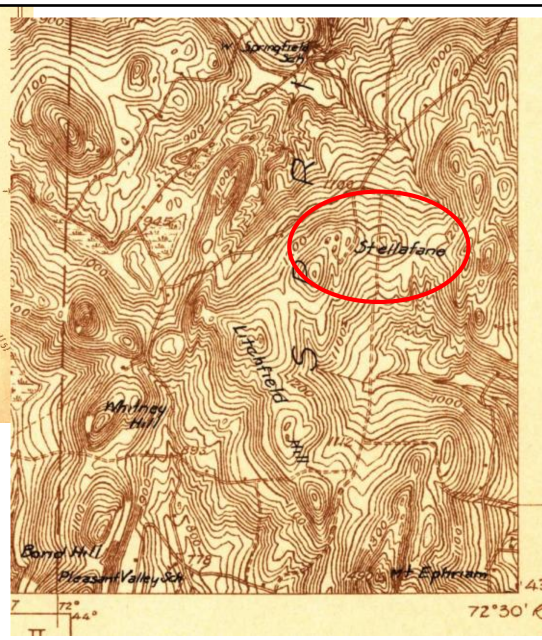

**Comparisons**

**Porter as an explorer: Opportunistic mapping over a limited time, one small field crew, lots of sketching. No opportunity to return and fix problems, lots of blank spots left on the map. Not always high final accuracy.**

**USGS: Systematic work by separate teams for triangulation and leveling, and multiple plane table teams in a quadrangle at the same time. Still lots of sketching. Final results checked and re-checked, no blank spots.**

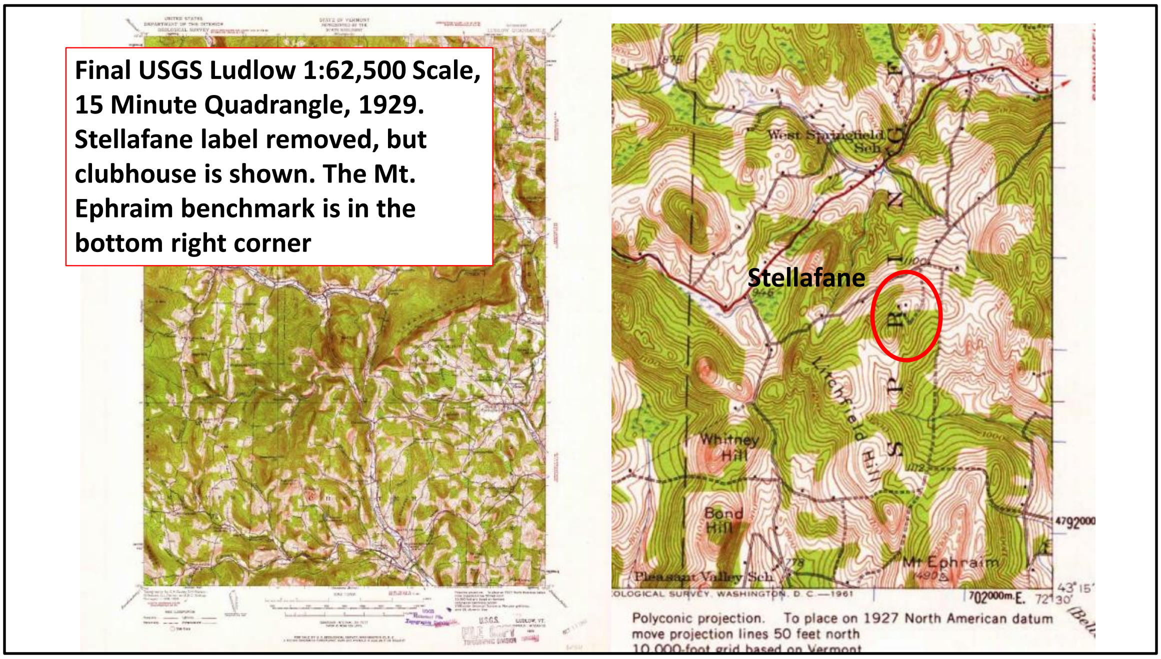




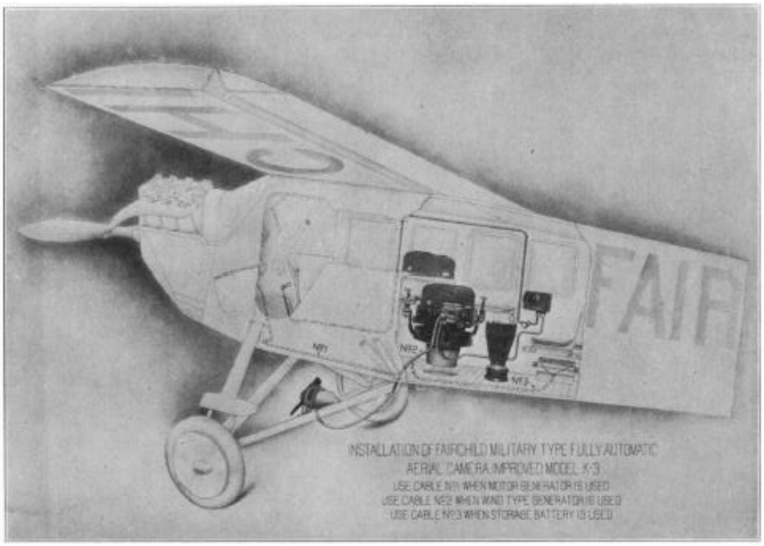




**Portions of a 1:48,000 Advance Sheet for part of the USGS Ludlow 15-minute Topographic Quadrangle Map, 1928. Used for quality control. Note that the Clubhouse is labeled on this sheet.**

Extensive office work was required to bring field sheets together into an accurate and standardized product. The Advance Sheet would have been sent to USGS and State officials for review and corrections.




For some reason the Stellafane name has been removed. No benchmark shown at the site.

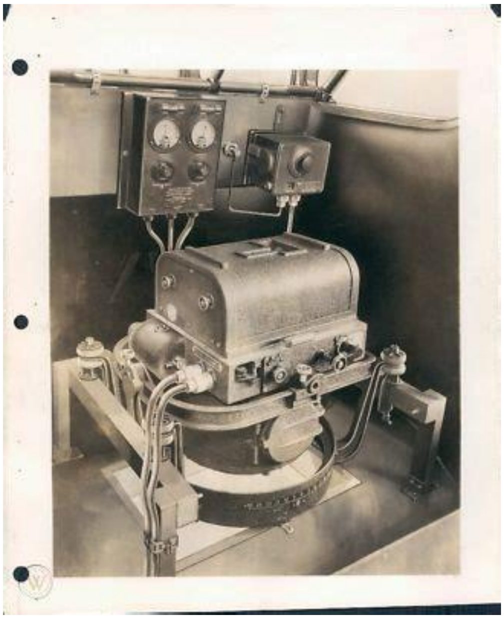


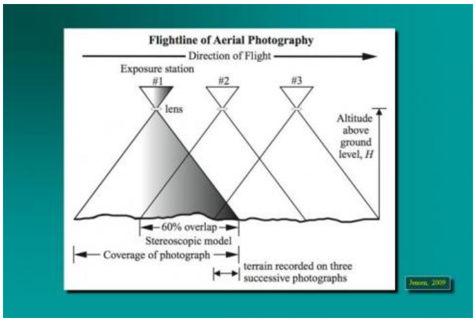

**The Future of Mapping**

**Aerial photography developed rapidly after the end of World War I. A 1927 view of a complete Fairchild aerial camera system, including camera, intervalometer, and viewfinder.**

**From Fairchild, S.M., 1927, Aerial photography: It's development and future: The Annals of the American Academy of Political and Social Sciences, v. 131, p. 49-55.**

Aerial photos were even used for some parts of the mapping of the Claremont quadrangle that was completed in 1929.






**Left: The Fairchild K-8 camera from 1928. Negative size is 9 x 7 ½ inches. A single roll of film could take 75 frames and backs were removable, meaning that hundreds of square miles could be covered in a single flight.**
**Above: Flightline layout for stereoscopic coverage.**

The careful overlapping of exposures allows adjacent pairs of aerial photos to be viewed with stereoscopic vision.


**Fine Detail: The Lower Jones and Lamson Shops and the Black River, Springfield**

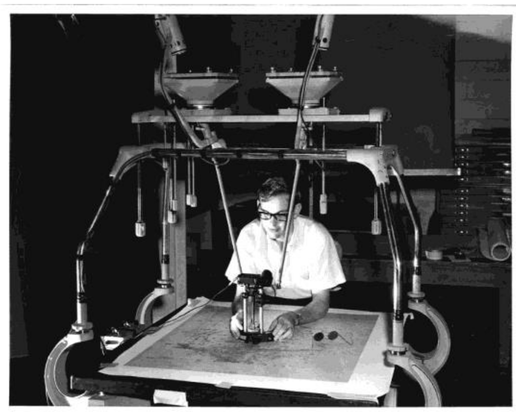
**Vertical aerial photo taken on May 8, 1962. Contact print from 9 x 9 inch negative. Scale 1:6,000 (1 inch = 500 feet). Shot with a 6 inch f.l. lens by Amman International Corp. for the State of Vermont.**

**Available online at**
**https://geodata.vermont.gov/pages/imagery**

The recently demolished Jones and Lamson plant is visible to the left of center on the west side of the Black River.

## Using Aerial Photos: Stereo Viewing

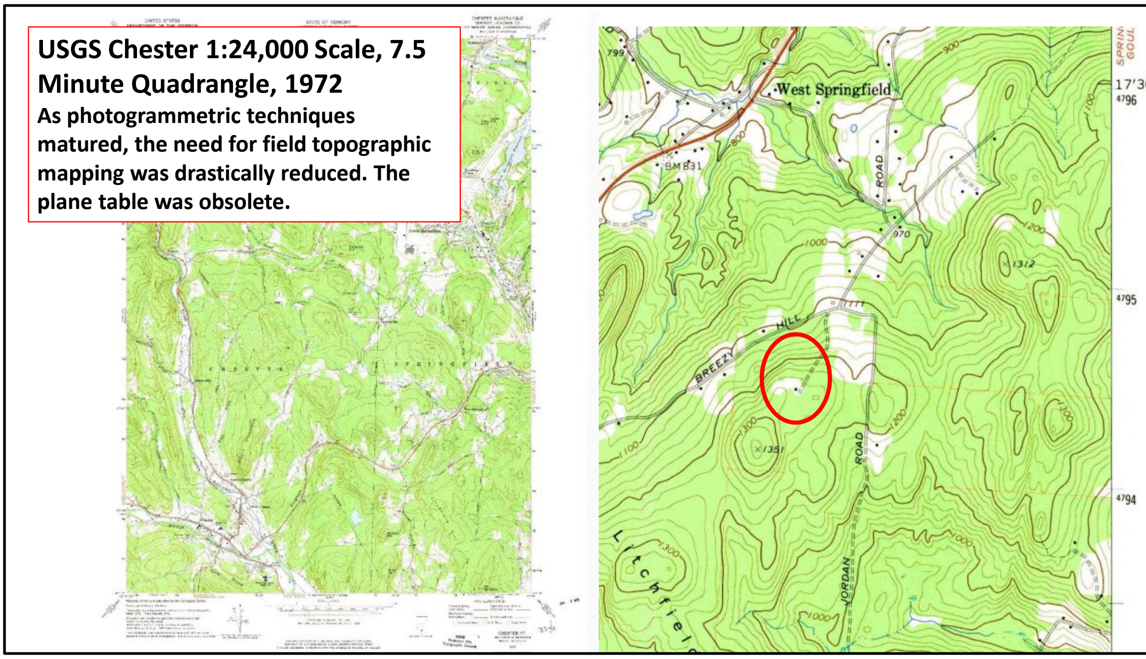
**Left: Viewing a pair of aerial photos in a stereoscope.**
**Right: Photogrammetric mapping using a Kelsh stereoplotter.**



**The stereoplotter could correct for camera tilt, radial displacement of features, and displacements due to changes in the elevation of the terrain.**

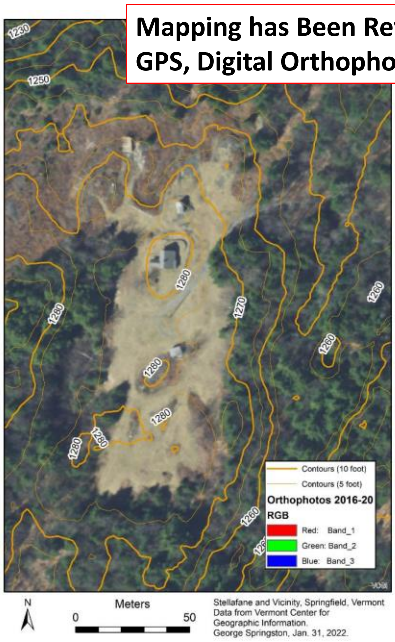
https://www.e-education.psu.edu/geog480/node/452

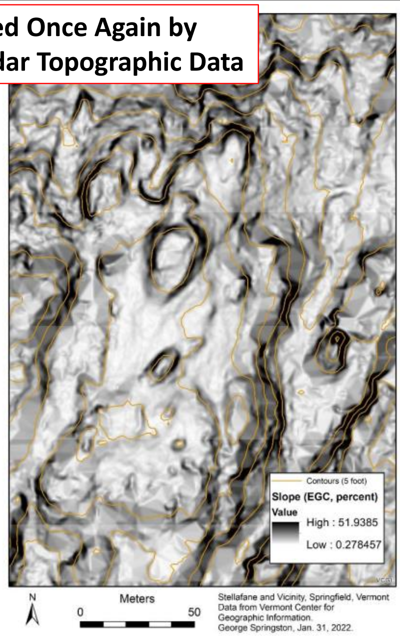
A simple stereoscope shows the terrain, vegetation, streambanks, and rivers in high relief. Interpretations can be sketched on one of the photos or sketched onto an existing map. The stereoplotter is needed for quantitative mapping of contours and features.




Maps such as this Chester quadrangle from 1972 were produced via photogrammetry and required only a few ground control points.

## Mapping has Been Revolutionized Once Again by GPS, Digital Orthophotos and Lidar Topographic Data




Orthophotos (left) are produced from rectified aerial photos. The slope map (right) shows steep areas as black and flat areas as white. Pixel size is 0.7 m.

**Summary**

**I never did track down why the benchmark is not on any map, but I do have an even greater appreciation than before for the work of Porter and the other mapmakers of that heroic age. And the benchmark can perhaps remain our little secret.**

**Thanks To:**

**Gail Weise, Archivist, Norwich University Archives and Special Collections, for images from *To the Top of the Continent.***

**Greg Saeur, Executive Director, Kreitzberg Library, Norwich University, for help with finding the historical topos.**

**References:**

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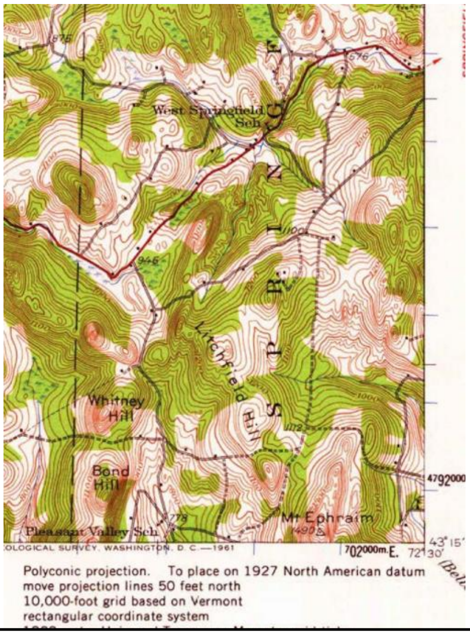


We now know where Stellafane is more precisely than ever. The benchmark is certainly the one placed by Wilson, but is ever so slightly unofficial.