After his discovery, Tombaugh took some time off to obtain his formal education in astronomy. He left for the University of Kansas in the fall of 1932, returning to Lowell each summer to resume his observing duties. At college, he met Patricia Irene Edson, a philosophy major. They married in 1934, and subsequently had two children. Tombaugh paused only once more for formal education in science, taking his master’s degree in 1939 at the University of Kansas. For his thesis work, he restored the university’s 27-in (68.6-cm) reflecting telescope to full operational status and studied its observing capabilities.

In 1943, Tombaugh taught physics at Arizona State Teachers College in Flagstaff; that same year, the U.S. Navy asked him to teach navigation, also at Arizona State. In what little spare time remained, Tombaugh struggled to continue the planet survey. The following year, he taught astronomy and the history of astronomy at the University of California in Los Angeles. Tombaugh’s stint on the planet survey ceased abruptly in 1946. Citing financial constraints, observatory director Vesto M. Slipher asked Tombaugh to seek other employment.

Tombaugh’s contribution to the “planetary patrol” at Lowell proved enormous. From 1929 to 1945, he cataloged many thousands of celestial objects, including 29,548 galaxies, 3,969 asteroids (775 of them previously unreported), two previously undiscovered comets, one nova, and, of course, the planet Pluto. However, as Tombaugh pointed out to biographer David Levy, tiny Pluto cast a long and sometimes burdensome shadow over the rest of his career, obscuring subsequent astronomical work. For instance, in 1937, Tombaugh discovered a dense cluster of 1,800 galaxies, which he called the “Great Perseus-Andromeda Stratum of Extra-Galactic Nebula.” This suggested to Tombaugh that the distribution of galaxies in the universe may not be as random and irregular as some astronomers believed at the time.

Tombaugh was also an accomplished observer of Mars. He predicted in 1950 that the red planet, being so close to the asteroid belt, would have impact craters like those on the moon. These craters are not easily visible from Earth because Mars always shows its face to astronomers fully or nearly fully lighted, masking the crater’s fine lines. Images of the Martian surface captured in the 1960s by the Mariner IV space probe confirmed Tombaugh’s prediction.

In 1946, Tombaugh began a relatively brief career as a civilian employee of the U.S. Army, working as an optical physicist and astronomer at White Sands Proving Grounds near Las Cruces, New Mexico, where the army was developing launching facilities for captured German V-2 missiles. Tombaugh witnessed 50 launchings of the 46-ft (14-m) rockets and documented their performance in flight using a variety of tracking telescopes. Armed with his observing skills and intimate knowledge of telescope optics, Tombaugh greatly increased the quality of missile tracking at White Sands, host to a number of important postwar missile-development programs.

Tombaugh resumed serious planetary observing in 1955, when he accepted a teaching and research position at New Mexico State University in Las Cruces. There, he taught astronomy, led planetary observation programs, and participated in the care and construction of new telescopes. From 1953 to 1958, Tombaugh directed a major search for small, as-yet-undetected objects near the Earth—either asteroids or tiny natural satellites—that might pose a threat to future spacecraft. He and colleagues developed sensitive telescopic tracking equipment and used it to scan the skies from a high-altitude site in Quito, Ecuador. The survey turned up no evidence of hazardous objects near Earth, and Tombaugh issued a closing report on the program the year after the Soviet Union launched Sputnik (1957), the first artificial satellite.

Upon his retirement in 1973, Tombaugh maintained his links to New Mexico State University, often attending lunches and colloquia in the astronomy department that he helped to found. He also remained active in the local astronomical society and continued to observe with his homemade telescopes. Indeed, asked by the Smithsonian Institution in Washington, D.C., to relinquish his 9-in reflector to its historical collections, Tombaugh refused, explaining to Smithsonian magazine, “I’m not through using it yet!” He died in 1997 at his home in Las Cruces, New Mexico.

Topography and topographic maps

Topography is the physical shape of the land, particularly as it relates to elevation. Topographic maps are two-dimensional graphical representations of the three-dimensional topography that also provide a detailed and accurate inventory of what exists on the land surface, such as geographic and cultural features.

Topographic maps are distinguished from other maps in their representation of elevation as contour lines. Contour lines are drawn to match the shape of physical features and successive contour lines represent ascending or descending elevations. This allows a user to quickly discern the shape of any landform, determine its elevation, and estimate the rate of elevation changes. For example, a round hill would appear as a series of concentric closed loops that become successively smaller with increased elevation. The closer the contour lines are to one another, the steeper the slope.

In addition to contoured elevations, topographic maps show many other features of the land, including names of natural features such as mountains, valleys, plains, lakes, and rivers. They identify the amount of vegetative cover and include constructed features like minor and major roads, transmission lines, and buildings. Topographic maps also show political boundaries, survey markers, and different map coordinate systems such as latitude and longitude.

The value of topographic maps is in their accuracy and consistency. Topographic maps are based on a rigorous geodetic base, which defines the shape of Earth over a given land area. This ensures that all included features will be shown in the exact position. All features on the maps conform to a consistent set of map symbols, allowing comparison of topographic maps from anywhere in the country.
The high accuracy and range of information of topographic maps makes them useful to professional and recreational map users alike. Topographic maps are used for outdoor activities like hiking, camping, and fishing and in professional fields such as engineering, energy exploration, natural resource conservation, environmental management, public works design, commercial and residential planning.

To meet the needs of various users, the United States Geological Survey produces topographic maps at different scales for the entire United States. The scale is the ratio of a unit of measurement on the ground to that on a map. For example, if one inch on a topographic map equals one mile (or 63,360 inches) on the ground, the scale of the map is 1:63,360. The most common scale for topographic maps is 1:24,000, where one map inch equals 2000 feet on the ground. This size map is called a 7.5-minute quadrangle because it covers 7.5 minutes of latitude by 7.5 minutes of longitude. Maps at this scale are very detailed. A map with a larger ratio, such as 1:100,000 will cover more area but show less detail.

See also Cartography; Relief

TORINO SCALE

Advanced by Massachusetts Institute of Technology Professor Richard P. Binzel in 1995, the Torino scale is a revision of the Near-Earth Object Hazard Index. In 1999, the International Conference on Near-Earth objects adopted the scale at a meeting in Torino (Turin), Italy (from which the name of the scale is derived). The Torino scale is used to portray the threat to Earth of an impact with a particular comet or asteroid. The measurement scale is based upon agreement between scholars as a means to categorize potential hazards.

When a new comet or asteroid is initially tracked, an extrapolation of its projected orbital path is compared to predicted Earth orbital positions. The Torino scale assigns categories to the closeness with which an object will approach or cross Earth orbit. Because initial estimates can be greatly altered by refined data regarding the track of an asteroid or comet, it is possible that a particular asteroid or comet could be upgraded or downgraded with regard to the threat it poses Earth. In addition, a different scale designation can be made for each successive orbital encounter over a number of years or decades. Data is most accurate as related to encounters in the near-term because various gravitational forces and encounters with other celestial objects can alter the course of asteroids or comets.

The Torino scale is based upon a zero to 10 numbering system wherein a zero designates a statistically negligible threat of collision with Earth. At the other extreme, a numerical designation of ten would indicate certain impact. In addition to being based upon the probability of impact, scale numbers also incorporate a potential "damage" value. For example, a very small object with little chance of surviving a fiery entry into Earth’s atmosphere will still be assigned a very low number (zero for very small objects) even if an impact was certain. At the other extreme, the designation 10 carries the ominous distinction of being reserved for a certain impact of cataclysmic proportions.

The size of an object is important because the force (kinetic energy) that it would carry in a collision with Earth is related to its mass and velocity. Like nuclear explosions, estimates of the energy of collision are given in units of megatons (MT).

The Torino scale also assigns colors to the potential hazard assessment. A “white” label means that the asteroid or comet poses no threat (i.e. will miss or not survive entry into the Earth’s atmosphere). Green events designate orbital crossings with a small chance of collision. Yellow events designate more potential orbital crossings than average. A yellow designation would focus intense scientific scrutiny upon the track of the asteroid or comet. Orange events are “threatening” crossings or other encounters with asteroids or comets that have a potential to cause severe destruction. The designation is reserved for objects with a significantly higher risk of impact. Red events or collisions are certain and globally devastating.

Because risk assessments are difficult to quantify, another scale, the Palermo Technical Scale, is often used by astronomers to complement the Torino scale. The Palermo scale offers a more mathematical calculation utilizing the variables of probability of impact and energy of collision.

As of May 2002, with approximately 25% of Near Earth objects identified, no object rating more than a “1” on the Torino scale has yet been detected. For example, during February 2002, an asteroid designated 2002 CU11 was classified as a “1” on the Torino scale (a “green” code). Extrapolations of the orbital dynamics of the asteroid and Earth indicated a low probability (approximately 1 in 9000) of a potential collision in 2049.