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A Bibliography of Geomorphometry, the Quantitative Representation of Topography—*Supplement 3.0*

By RICHARD J. PIKE [1]

Provides over 900 additions and corrections to the 1993 Bibliography of Geomorphometry and its 1995 and 1996 Supplements, with an update of recent advances

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A Bibliography of Geomorphometry, the Quantitative Representation of Topography—*Supplement 3.0*

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Abstract This report adds over 900 references on the numerical characterization of topography (*geomorphometry*, or *terrain modeling*) to a 1993 review of the literature and its 1995 and 1996 supplements. A number of corrections are included. The report samples recent advances in several morphometric topics, featuring six in greater depth—landslide hazards, barchan dunes, sea-ice surfaces, abyssal-hill topography, wavelet analysis, and industrial-surface metrology. Many historical citations have been added. The cumulative archive now approaches 4400 references.

The practice of terrain quantification continues to grow through its many applications to geomorphology, hydrology, geohazards mapping, tectonics, and sea-floor and planetary exploration. Geomorphometry (or simply *morphometry*) is an amalgam of Earth science, mathematics, engineering, and computer science. It is known variously as *terrain analysis* or *quantitative geomorphology*, although the newer term *terrain modeling* increasingly seems to be preferred. Dating back at least to Humboldt (1843a, b) and Ritter (1852), the discipline has been revolutionized by the computer manipulation of square-grid arrays of terrain heights, or digital elevation models (DEM's), that quantify and portray ground-surface form over large areas (Florinsky, 1998a, b). Morphometric procedures are now implemented routinely by geographic information systems (GIS) and other computer software.

This is the third update of a bibliography and introductory essay on geomorphometry (Pike, 1993, 1995, 1996). The purpose of these reports is to draw together the diverse, scattered literature on surface characterization and make it accessible to the research community—typically at two-year intervals. The need for a running archive of citations remains clear from the accelerating use of DEM's, at all resolutions, in many areas of science and technology—including manufacturing (Thomas, 1999). Here I add more than 900 items to the 3400-odd entries contained in the earlier three reports[1]. Some 20 references (p. 56-57) correct the most serious errors found in the three listings. The new entries in this report include both publications postdating the second supplement (current through mid-1996) and many older works overlooked previously. Coverage is representative, but not exhaustive, through late 1998.

The appended listing is alphabetized and largely unannotated, following the format of its two predecessors, although recently I have begun to append brief notes to most citations. The 60-topic organization of geomorphometry developed initially (Pike, 1993, Table 2) still accommodates the latest entries. The same qualifications and caveats on accuracy and completeness stated earlier apply equally to this third supplement. The combined reference file now is nearing 4400 entries (a 1-Mb digital file). Preparations for distributing the cumulative bibliography in digital form and over the Internet continue but remain incomplete. Similarly, no plans for sorting the listing topically or chronologically have been finalized (the file is not encoded in specialized bibliographic software). Earlier references to morphometry on the Internet (Pike, 1996) have been updated and 70 World Wide Web addresses published (Pike, 1998).

[1] The few text citations not in the main bibliography (p. 10-56) are on either p. 9 or in 'Corrections' (p. 56-57).

Noted here briefly are advances in established areas of morphometric research since the last supplement. Progress in industrial-surface metrology has been sufficient to warrant a substantial update. A selection of early (pre-1900) morphometric work is also included, and two important new books are described. In continuing the practice of previous reports, to feature several active—if not necessarily new—areas in which morphometric analysis plays a central role, here I briefly review work on landslide hazards, barchan dunes, sea-ice surfaces, sea-floor abyssal hills, and wavelet analysis. The literature in most of these areas is vast, and none of my summaries is intended to accomplish more than introduce each topic and then guide the reader into its morphometric aspects.

Landslide hazards

Slope failure exacts a costly "environmental tax" on society, and the resulting expenses are mounting worldwide as many urban centers expand from early-settled flatlands into surrounding hills. Widespread winter damage from landslides across coastal California during the 1997-98 El Niño exemplifies the need to reduce this economic penalty by better understanding the hazard and its spatial distribution (El Niño Response Group, 1998; http://elnino.usgs.gov/landslides-sfbay/). Because landslide activity correlates closely with ground-surface slope and other attributes of terrain form that can be measured from DEM's (Brabb and others, 1989), slope-failure is perhaps the natural hazard most amenable to study by quantitative techniques (Soeters and van Westen, 1996). Much of the morphometric literature on landslides is referenced in the first report in this series (Pike, 1993).

Two overall approaches, not sharply distinguished in many publications, employ quantitative topographic data to analyze processes of slope failure—the landslide-specific and the regional. By the first, and older, approach landslides are treated individually, as discrete landforms. Measurements, usually from field surveys or contour maps, are taken of such variables as landslide length, breadth, volume, planimetric shape, compass orientation, and height of head scarp. These quantities are compared with each other and with bedrock and soil properties, local hydrology, and other physical characteristics to isolate causative factors and model the physics of the process (Bhandari and Kotuwegoda, 1996; Hylland and Lowe, 1997).

Increasing availability of large square-grid DEM's and GIS technology has led to the use of the second, regional, approach whereby slope angle, curvature, relative relief, and other measures that relate to landsliding are computed continuously over broad areas (Carrara and others, 1995; Mark and Ellen, 1995). Digital maps of geology, materials properties, and landslide inventories are then compared and combined with those maps of terrain geometry to obtain a set of variables that can be used to delineate potentially hazardous areas (Brunori and others, 1996; Fernández and others, 1996; Ellen and others, 1997).

In carrying out such regional modeling it is critical to distinguish among different processes of slope failure. The topographic and geologic conditions triggering debris flows, for example, differ markedly from those giving rise to slumps, slides, and earthflows. Recent work on debris flows that incorporates DEM-based morphometry is described in Boelhouwers and others (1998), Dietrich and others (1995), Campbell and others (1998), Walsh and Butler (1997), and in a book edited by C.-L. Chen (Campbell and Bernknopf, 1997; Wieczorek and others, 1997). Proceedings volumes edited by K. Senneset (Chandra, 1996) and by Chacón and others (Fernández and others, 1996) address morphometric analysis of slope failure other than debris flow.

Barchan dune morphometry

Barchans are migrating sand dunes that pose a hazard to dwellings, highways, railroads, and other infrastructure of desert settlements (Beadnell, 1910; Al-Janabi and others, 1988; Khalaf and Al-Ajmi, 1993). These crescentic dunes are unique among landforms in that size, shape, degree of complexity, and location all can change markedly over the life of the feature (Bagnold, 1941, p. 208-221; Norris, 1966).

Modeling the development and migration rate of barchans is facilitated by the crisp definition and consequent ease of measurement of isolated dunes (Howard and others, 1978). In the search for clues to barchan-forming processes, dune length, cusp-to-cusp width, slip-face height and overall height, differences in cusp length, and dune volume all have been measured and compared. Some of these dimensions correlate with dune spacing, rate of movement, wind direction, and sand supply (Lancaster, 1989a,b; Shehata and others, 1992; Haff and Presti, 1995). Such relations are vital in predicting the speed and trajectory of migrating barchans.

The morphometry of barchans currently is unsystematic in several respects, which impedes the understanding of process and evolution of form. For example, available measurements do not cover the observed size-range; in plan dimensions, barchans vary from soup-plate size (Norris, 1956) to several hundreds of meters across (Bagnold, 1941; Embabi and Ashour, 1993). Although a 1:10 height:width relation commonly is assumed for barchans from published measurements (Hesp and Hastings, 1998), data from other areas (Embabi and Ashour, 1993) do not support this generalization, even across the size-range for which measurements exist. Graphs in a recent compilation of some published dimensions (Hesp and Hastings, 1998) suggest that barchan height may be a non-linear function of size, but no attempt has been made to test for size-dependency of form. Also, barchans in the Middle East (Embabi and Ashour, 1993) and the Sahara (Sarnthein and Walger, 1975) may be larger than those measured in Peru (Hastenrath, 1967, 1987) and the western United States (Long and Sharp, 1964). Nor has it been determined whether the size-frequency distribution of barchans is normal or otherwise.

To address these problems, fresh measurements are needed to adequately represent the entire size-range, particularly the smaller barchans—which move so fast and are so ephemeral that they tend not to be measured (Norris, 1956). Much work remains before barchan systematics are sufficiently well established to support robust form-process modeling throughout the observed size-continuum (Mulligan, 1995).

Morphometry of sea-ice surfaces

A hazard to winter navigation and a danger to such offshore structures as oil pipelines, sea ice is an ephemeral, seasonal and continually changing landscape of the high latitudes. Sea ice may be either undeformed, as initially frozen, or deformed by a number of processes. A field of deformed sea ice is level overall, but its mesoscale morphology (only a few meters of relief) can be very rough because of varying forms of ridged ice (Weeks and Kovacs, 1970). *Pressure ridges* are irregular slabs of ice imbricated by wind and other agents. Although complex objects that vary greatly in size and shape, these ridges appear to be limited in vertical extent (Parmerter and Coon, 1972). Ridge morphology above and below the sea surface can be represented statistically from measurements of salient features. Kankaanpää (1997) gives a good recent sampling of the voluminous literature. Earlier morphometric work on sea ice includes Hibbler and Mock (1974), Wadhams (1981), Williams and others (1975), Rothrock and Thorndike (1980), and Wadhams and Davy (1986).

The surface relief of pressure ridges is measured by standard field methods of ice surveying—drilling, sectioning, and photography (Kankaanpää, 1997), as well as by sonar (McLaren, 1988), laser profiling (Lewis and others, 1993), and other techniques of remote sensing. Detailed measurement of ridge morphometry accelerated during the Cold War, when high-latitude terrains were anticipated as potential battlefields. The underside topography of floating ice was systematically profiled to assist submarine operations (Williams and others, 1975; McLaren, 1988).

The *sail* is that portion of a pressure ridge above the surrounding ice surface; the (much larger) portion projecting below the water surface is the *keel*. The size, shape, spacing, and areal density of sails and keels have been investigated by various techniques (Wadhams and Davy, 1986; Kankaanpää, 1997). Size-frequency distributions of such sail and keel parameters as height, depth, width, cross-sectional area, and slope angle have been determined for different ice packs and compared with each other and with theoretical models (Lowry and Wadhams, 1979).

Pack-ice surfaces have also been modeled statistically by the variance (power) spectrum and other techniques of random-field analysis (Lewis and others, 1993). Among generalizations reached thus far: new (first-year) ridges differ significantly from older (multiple-year) ridges and sail height is related to keel depth (Timco and Burden, 1997; Kankaanpää, 1997); ridge size, but not shape, differs from sea to sea (McLaren, 1988; Kankaanpää, 1997) and with ridge age (Timco and Burden, 1997); and keel profiles appear to have a fractal distribution (Melling and others, 1993).

Abyssal hills on Earth's sea floor

Abyssal hills are small, elongate features created at mid-ocean-ridge spreading centers by faults that offset fresh basaltic sea floor (Pratson and Haxby, 1997; Smith, 1998). These hills are the most common morphologic feature on the ocean floor, arguably rivaling subaerial drainage basins in frequency, but they remain among the least understood of Earth's landforms. Because abyssal-hill morphology reflects processes and rates of ridge-crest spreading (Ma and Cochran, 1997), abyssal-hill topography constitutes a major piece of the overall plate-tectonics puzzle. A number of generalizations were established earlier: both simple and complex morphologies are observed, hills in the Atlantic ocean basin are larger than those in the Pacific, and both volcanic and tectonic processes evidently are involved in their origin (Menard, 1967).

As deep-sea imaging has improved in resolution and areal coverage, morphometry has played an expanding role in probing the nature of abyssal hills. Because individual hills are still too small to be measured accurately by available imaging systems (Vogt and Tucholke, 1986; Smith and Sandwell, 1997), the hills are analyzed as continuous swaths of textured topography (Goff and Jordan, 1988; Shaw and Lin, 1993; Goff and others, 1997). Among the generalized measures by which this texture is captured are relief, azimuth, slope, slope curvature, ridge-parallel spacing, ridge-normal spacing, and the proportion of coarse- to fine-scale roughness (Goff and Jordan, 1988; Shaw and Lin, 1993). Recently, Small (1994) and Ma and Cochran (1997) have statistically distinguished abyssal-hill roughness from the basic shape of the ridge axis, and processes other than faulting and volcanism have been found to modify the hills (Goff and Tucholke, 1997). In attributing abyssal hills to stretching of the oceanic lithosphere, Buck and Poliakov (1998) further suggest that the process exhibits self-organized criticality.

Abyssal-hill topography is most recently discussed by Goff (1998), who contrasts analytic approaches to these surface forms as either *continuous* or *discrete*. Emphasizing the chaotic appearance of continuous abyssal-hill terrain, "observationalist" workers treat the problem more stochastically, via second-order statistics of hill dimensions and spacing (Goff and Jordan, 1988; Goff and others, 1997). The "physical modelers", in contrast, emphasize the regular spacing of discrete deep-sea faults and their offsets in the hilly terrain and thus address the issue more deterministically (Shaw and Lin, 1993; Malinverno and Cowie, 1993). The detailed modeling of Buck and Poliakov (1998) is important because it begins to reconcile the two approaches (although much remains to be done).

Goff (1998) closes his methodological discussion with comments on the fractal concept. In a caveat that extends beyond abyssal hills to other aspects of terrain modeling (for example, Gallant, 1997, and Evans, 1998), he cites the "gulf between merely describing the statistical behavior of a natural phenomenon ... and understanding the physical principles which lead to such behavior..." By implication, self-organized criticality is the latest such "scientific bandwagon" (see also Agterberg, 1998, Bhattacharya, 1997, and Traut, 1998), as investigators try "... to understand how this 'new' ... way of thinking about nature might bear on their particular specialty."

Wavelet analysis of landforms

Scale-dependence of the ground surface, particularly since the advent of fractal measures (Mandelbrot, 1975), has become a key research area in much of morphometry (Moore, Lewis, and Gallant, 1993; Blöschl and Sivapalan, 1995; Bishop and others, 1998). The problem is addressed by analyzing relief *(Z)* and planimetric *(X,Y)* attributes of topography over several spatial scales, either for areally discrete *landforms* or over continuous-surface *landscapes.* In pursuing the latter approach, Gallant & Hutchinson (1996) and Gallant (1997) found the fractal concept wanting and as a consequence Gallant has introduced *wavelets* to landform morphometry. This analytical method decomposes a topographic surface into a set of oscillatory functions at different frequencies in a similar manner to the Fourier transform in spectral analysis. The wavelet transform employs localized functions (wavelets) rather than infinitely repeating sine and cosine functions. Among its advantages over the elevation-variance spectrum are an improved representation of azimuthally non-homogeneous terrain and the provision of spatially variable descriptions. To accomplish this, the process superposes multiple mathematical "features" at various scales.

The modeled feature chosen by Gallant to develop the method on representative Australian DEM's has an elliptical plan and a smooth polynomial profile, the simplest geometric form with sufficient flexibility to represent most topographic surfaces. Gallant's (1997) examination of scale and spatial structure of relief in continuous topography has identified at least three descriptive parameters—terrain "complexity," "positivity," and "orientation"—attributes which almost certainly relate to descriptors computed by other approaches to terrain quantification. Work is needed to investigate possible correlations. The results of Gallant's pioneering work are difficult to judge now, because relatively few other wavelet studies have been carried out on natural topography (Foufoula-Georgiou and Kumar, 1994; Weissel and Stark, 1997; Kumar and Foufoula-Georgiou, 1997; and three others listed in Pike, 1995, 1996).

Metrology update

Industrial surface-metrology (hereafter *metrology*[2]) is the quantification of micro- and nano-scale surfaces in manufacturing (Pike, 1996). The explosive expansion of metrology, driven most recently by research in high-technology industries and far outstripping the growth of its parallel discipline of topographic quantification, is paced by three important new books. Thomas (1999) revises a standard 1982 text weighted toward mechanical engineering, and Bhushan (1997) has updated developments in the metrology of magnetic tape and computer disk drives. The proceedings of a 1996 conference on metrology and the properties of engineering surfaces ("the best we've ever had", T.R. Thomas, 1998, pers. comm.) were published in 1997 (Rosén and Crafoord, eds., 1997). All three volumes contain industry analogs of Earth-surface terrain quantification, including fractal modeling, self-organization, power-spectral and wavelet representation, and functional linkages between form and process. Two slightly older books, the standard handbook on metrology (Whitehouse, 1994) and a manual of methods for 3-D characterization of surfaces (Stout and others, 1993), are no less significant.

Recent shorter works on the topography of industrial surfaces include Bhushan and Koinkar (1995), Mainsah and others (1996), He and Zhu (1997), and Othmani and Kaminsky (1998). Hähner and Spencer's 1998 review of the related field of tribology—the study of friction, lubrication, and wear—is helpful background. A paper by Medeiros-Ribeiro and others (1998) is of particular interest. They have revealed and quantified a nanoscopic transition, from smaller pyramids to larger domes, in the morphology of germanium crystals grown on a silicon substrate by physical vapor deposition. The size-dependent change, which conceptually resembles the transition from central peaks to inner rings in large planetary impact craters (Pike, 1982), is marked by pyramids that "... nucleate and grow to a maximum volume that is smaller than the volume for which the domes are more stable than the pyramids plus (a critical volume of added) germanium ..." This transition, which seems to mark a shift from one equilibrium form to another with increasing input of energy or material, may have other geomorphologic parallels that help to explain size-dependent differences observed in some landforms.

Many publications on industrial-surface metrology are referenced in a new, chronologically ordered, bibliography that

[2] The discipline commonly is known within industry—albeit somewhat confusingly to Earth scientists—as *surface topography*. A specialized journal of that same title existed briefly from 1988 to 1990.

improves access to research on surface quantification not found in the usual geomorphology-related sources (Pike and Thomas, 1998). A brief essay prefacing the 4800 literature citations introduces metrology to Earth scientists, describes similarities and differences between the two realms (Scott, 1994, 1997), and raises issues that must be addressed in any attempt to unify the practice of surface quantification. A sampling of Internet Web-site addresses and full abstracts of papers on metrology rounds out the main listing.

Other recent morphometry

More conventional areas of morphometry continue to thrive as well. Several of these are described above. A most important new development is the rapid increase in publication exclusively by CD-ROM and by posting on the Internet (Pike, 1998). Recent major contributions include Joseph Wood's thesis on digital terrain modeling (http://www.geog.le.ac.uk/jwo/research/dem_char/thesis/); two software packages for the hydrogeomorphic analysis of DEM's—Scott Peckham's RiverTools (http://cires.colorado.edu/people/peckham.scott/RT.html) and David Tarboton's TARDEM (http://www.engineering.usu.edu/cee/faculty/dtarb/dem.htm); proceedings of the 1996 Santa Fe, NM, GIS Conference and Workshop (http://ncgia.ncgia.ucsb.edu/conf/SANTA_FE_CD-ROM/sessions.html); and the latest release of Peter Guth's MicroDEM+ terrain-modeling software (http://www.usna.edu/Users/oceano/pguth/website/microdem.htm).

Briefly, other new developments include:

- the morphometry of continental ice surfaces (Bahr, 1997; Etzelmüller and Sollid, 1997); Davis and others, 1998; Scambos and Fahnestock, 1998; Tabacco and others, 1998;
- calculation of the DEM-to-watershed transformation (Tarboton, 1997; Rieger, 1998), with special attention to problems posed by low-relief topography (Garbrecht and Martz, 1997a; Martz and Garbrecht, 1998) and the inclusion of lakes (Fern and others, 1998; Mackay and Band, 1998);
- new DEM databases (Clayton and Shamoon, 1998a, b ; Smith, 1998; Welch and others, 1998);
- geomorphologic modeling other than that reported in the 1998 book edited by Lane and others (Ahnert, 1996; Tarboton, 1996; Ahnert and Williams, 1997; Beven and Kirkby, 1997; Costa-Cabral and Burgess, 1997; Willgoose and Hancock, 1998);
- characterization of glacial U-valleys (Duncan and others, 1998; Pattyn and Van Huele, 1998) and cirques (Hassinen, 1998; Sauchyn and others, 1998);
- DEM-based tectonic geomorphology (Seber and others, 1997; Demoulin, 1998);
- geometric and geomorphic signatures (Sulebak and others, 1997; Brown and others, 1998; Giles, 1998; Giles and Franklin, 1998);
- characterization of fractured rock surfaces (Glover, 1998a, b);
- morphometric applications to soil development and agriculture (Thompson and others, 1997; DeBruin and Stein, 1998; Florinsky and Arlashina, 1998; Souchere and others, 1998);
- the geometry of seamounts (Smith and others, 1995; Rappaport and others, 1997; von Huene and others, 1997; Wessel, 1997);
- planetary surface features (Craddock and Maxwell, 1997; Yingst and Head, 1997; Oberst and others, 1997; Kreslavsky and Basilevsky, 1998; Smith, Zuber and others, 1997, 1998; Williams and Zuber, 1998);
- pre- and post-eruption morphometry of volcanic edifices (Mizukoshi and others, 1995; Jones and Newhall, 1996; Mizukoshi and Murakami, 1997); and
- large-area visualization of topography by computer graphics, exemplified by, respectively, Australia, Alaska, and Earth's seafloor (Milligan and others, 1997; Riehle and others, 1997; Smith and Sandwell, 1997).

New books

Book-length publications that showcase advances in morphometry continue to appear. Among the most important recent additions outside of industrial surface-metrology are those by Rodríguez-Iturbe and Rinaldo (1997), Lane and others, eds. (1998), and Marcus and others (1996). The last volume, on biological objects, is a major development in non-topographic morphometry.

However, because it focuses on the representation of closed two- and three-dimensional forms only (sedimentary particles, mineral grains, fossils, tree leaves), notably through the "landmark analysis" pioneered by Bookstein (1995), its application to surfaces *per se* is limited.

Appearance of the monograph by Rodríguez-Iturbe and Rinaldo (1997) is a major event. Linking two modern concepts, fractal geometry and the theory of self-organized criticality, it addresses the fundamental nature of river basins and their structure and evolution. The book contains much more than just these two concepts, and treats the complexities of both spatial (planform) and temporal structures and patterns. Building on voluminous published work with colleagues, Rodríguez-Iturbe and Rinaldo synthesize a conceptual and mathematical framework within which the great variety of river networks—spanning some five orders of magnitude, 100 m to 10,000 km—and the underlying order can be studied. This *tour-de-force* in applied science includes enough background material to be largely self-contained. It contributes to physics as well as to theoretical hydrology and other geomorphically-oriented aspects of Earth science. For reviews see Agterberg (1998), Levy (1998), Tsonis (1998), and Turcotte (1998).

The proceedings of the 1995 Cambridge Fitzwilliam Symposium of the British Geomorphological Research Group (Lane and others, eds., 1998), reprises an important meeting (and 1972 proceedings volume edited by R.J. Chorley) held in England a quarter of a century earlier. Edited to a high standard, the 19 diverse chapters in the 1998 book offer a good sampling of contemporary morphometry—particularly in the UK. Included are McCullagh on Quality, use and visualization in terrain modelling, Evans on What do terrain statistics really mean?, Wise on The effect of GIS interpolation errors on the use of digital elevation models in geomorphology, Wilson and Gallant on Terrain-based approaches to environmental resource evaluation, Montgomery and others on The role of GIS in watershed analysis, Lamb and others on A generalized topographic-soils hydrologic index, and Lane on The use of digital terrain modelling in the understanding of dynamic river channel systems.

Early morphometry

Here I begin to remedy a shortcoming of previous reports in this series, neglect of old work in morphometry—much of it in languages other than English. These (annotated) citations both constitute the early history of the field and provide context for later work (Dainville, 1958, 1970). Addition of much of the older material began with my finding discrepancies in published literature citations of Alexander von Humboldt. (His prolific career spanned 70 years of active publication in various languages.) This discovery led to inspection of one of the several von Humboldt bibliographies (Löwenberg, 1960; itself not free of contradictory entries), with ensuing correction of errors in Pike (1993, 1996) and the addition here of six more papers by von Humboldt. Exposure to this pioneering morphometry prompted inclusion of other work, for example that of Carl Ritter (1852)—regarded by many, with von Humboldt, as the founder of the craft. However, any attempt to identify an "ultimate" origin for geomorphometry would be fruitless. The earliest systematic measurement of topography—undoubtedly predating Roman hydrology, Greek geodesy, and Egyptian civil engineering—is "lost in antiquity."

Some 60 pre-1900 references, the oldest of which is to the isobath map by Buach (1756), are added here. Most of the early writing describes efforts to accurately measure terrain height (Humboldt, 1817) and produce good contour maps (Du Carla, 1782), the primary source material for morphometry *per se* until advent of the DEM. Securing good elevations with spirit level and aneroid barometer was cutting-edge work in its day (Allen and Woods, 1817; Cuvier and Brongniart, 1835, p. 597-607; Pick, 1855), and the need to measure so elementary a quantity as surface height has not diminished—only the instrumentation has changed. The role of barometer and level has passed to such satellite-borne technologies as GPS and digital radargrammetry. The accurate determination of surface elevation poses a special challenge to planetary scientists (Smith and others, 1998; Williams and Zuber, 1998) and geophysicists working with seafloor terrain (Smith, 1998).

A number of the references added here are neither old enough to be of great historic interest nor sufficiently recent to bear directly upon contemporary work. They are valuable, however, in establishing a continuous historical record of geomorphometry as the field developed in several countries, from Humboldt and Ritter to Horton, fractals, and DEM's (Beer and Mädler, 1837; Schmidt, 1856; Höfer, 1879; Peucker, 1892; Romer, 1911; Horton, 1914; Blanchard, 1919; Jones, 1924, 1951; Matui, 1930; Burckhardt, 1934; Hollingworth, 1931, 1938; Cressy, 1938). This report also adds a dozen papers by Polish geographers, active contributors to morphometry in the 1920's and 1930's (Joerg, 1933), to better represent Eastern European work (Pawlowski, 1929; Zaborski, 1931; Strada, 1932). Several additions to later Soviet-era morphometry have been identified as well (Zakharov, 1940; Sharapov, 1967; Leder, 1973; Devdariani, 1976; Piriev, 1986; Lastochkin, 1987; Yakimenko, 1990).

New entries

As before, I encourage additions and corrections to this archive from its users. I am especially interested in morphometric work that is unlikely to be available in the United States, for example, non-English-language publications from central and eastern Europe. My files on French work also are inadequate. I will be happy to exchange copies of reports in this series for those papers. To ensure accuracy and reduce ambiguity, please send reprints or photocopies of contributions rather than just the citations, if possible. However, I can add new entries from only the following information:

1. photocopy of title page, or
  - title of the work, and
  - the name(s) of author(s); surname plus two initials (or, if one given name, then spelled out)
2. year of publication
3. *complete* citation of serial or other form of publication (book, conference proceedings, and so forth), including volume number, issue number, and inclusive pages. For meetings give location and dates; for books the name of city and publisher
4. for non-English-language publications, an English translation of the title.

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-------- 1995, A bibliography of geomorphometry, the quantitative representation of topography—Supplement 1.0: U.S. Geological Survey, Open-file Report 95-046, 30 p. [paper copy only; 124 kb if in digital format]

-------- 1996, A bibliography of geomorphometry, the quantitative representation of topography—Supplement 2.0: U.S. Geological Survey, Open-file Report 96-726, 52 p. [paper copy only; 228 kb if in digital format]

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