

Reprinted from Geller, E. (managing editor) 2000. *McGraw-Hill yearbook of science and technology 2001*. McGraw-Hill, New York, p. 296-300.

contemporary environments together with changes in human demography complicates identification of potential carcinogens or promoting factors. In question is whether the investigation of cancer in dinosaurs could provide useful insights for tackling this human malady. Identifying the frequency of cancer in past living creatures requires that cancer be recognized. Evidence that tumors existed in dinosaurs is derived from the fact that dinosaur bones are large and therefore, relatively well preserved over long periods of time. Tumors in soft tissues and tumors in species with smaller bones may not be recognized in past eras because of insufficient remains. Although the vertebrate paleontologic record is predominantly limited to bone, frequent involvement of bone by metastatic cancer means that the question can be explored. However, only one-third of metastatic cancer is identifiable by just looking at the bone surface. Fortunately, x-rays provide the opportunity to see the metastatic cancer, without destroying the bones. Preliminary x-ray study suggests that not all dinosaurs developed neoplasms, or at least that some families did so at much higher frequencies than others. Examination of frequencies and family specificity of cancer in dinosaurs may provide insights to etiologic agents and predisposing environmental factors.

Many aspects of the life of dinosaurs may be discovered by studying their diseases. Developmental disorders provide insight into bone growth and adaptation to huge body mass; infections (secondary to injury) provide insight to interspecies and intraspecies behaviors (mating pattern, hunting techniques, and so on); and metabolic disorders (such as gout) open a small window to dinosaur physiology. The long history of tumors may reveal something about the interaction between a species and the diseases it encounters. When humans affect the environment, the changes such as increased frequency of cancer can be adverse to the existence of a species. It should be noted that other natural phenomena changing the environment rapidly can also result in tumors.

For background information see CANCER (MEDICINE); DINOSAUR; FOSSIL; MESOZOIC; PALEONTOLOGY in the McGraw-Hill Encyclopedia of Science & Technology.

Bibliography. B. M. Rothschild et al., Mesozoic neoplasia: Origins of haemangioma in the Jurassic age, *The Lancet*, 351:1862, 1998; B. M. Rothschild and L. Martin, *Paleopathology: Disease in the Fossil Record*, CRC Press, London, 1993; B. M. Rothschild, B. J. Witzke, and I. Hershkovitz, Metastatic cancer in the Jurassic, *The Lancet*, 354:398, 1999.

### Paleosols

Paleosols, or ancient soils, are now widely recognized in ancient sedimentary and volcanic rocks, and along major geological unconformities as old as

3500 million years. They provide information, independent from the fossil record of organisms, for terrestrial environments, plant evolution, atmospheric composition, and global change in the past.

**Early life on land.** Much early debate on whether Precambrian weathering profiles should be called paleosols concerned evidence for life in them. Life need not be a definitive criterion for a soil or paleosol, as is shown by common usage of soil to describe lunar and Martian surfaces. In any case, the isotopic composition of carbon within Precambrian paleosols reveals not only life but a variety of life. Unusual excesses of the light carbon isotope ( $^{12}\text{C}$ ) compared with the heavy stable carbon isotope ( $^{13}\text{C}$ ) in organic carbon of a paleosol 2765 million years old from Mount Roe, Western Australia, are evidence of methanotrophic microbes and of atmospheric methane at that time. Another paleosol, from Schagen in South Africa, some 2560 million years old, has a heavy mix of carbon isotopes like those of saline desert soils. Isotopic values of carbon normal for soil biota are also found in Precambrian paleosols, including some as old as 2450 million years near Elliot Lake, Ontario. It is also remarkable, given this isotopic evidence for a variety of microbial life on land, that Precambrian paleosols have remained relatively clear of organic matter like most Phanerozoic paleosols. Some kind of decomposer microbial community must also have lived within Precambrian paleosols.

**Atmospheric oxidation.** Many Precambrian paleosols are deeply and thoroughly weathered, with clayey alteration around corestones reaching 10 m (30 ft) or more down into crystalline bedrock. They provide direct evidence for weathering by hydrolysis, presumably in dilute solutions of carbonic acid from a carbon dioxide greenhouse. Despite this evidence for long-term weathering of stable, well-drained landscapes, paleosols at geological unconformities older than about 2000 million years have remained gray-colored and little oxidized because of the scarcity of oxygen in the atmosphere at that time. Although biological reduction of these soils could have played a role in keeping them unoxidized, this has not prevented comparable well-drained Phanerozoic paleosols from being highly oxidized, and pigmented with red hematite. Red oxidized paleosols appear in the rock record by 2000 million years, though geochemical modeling of their oxygen consumption indicates less atmospheric oxygen at that time than during the past 800 million years. Mass balance modeling of the global carbon cycle over the past 500 million years, supported by carbon isotopic data from sediments and paleosols, has shown considerable fluctuation in atmospheric oxygen and carbon dioxide abundance. Comparable variation also can be inferred for the Precambrian (Fig. 1).

**Ordovician greenhouse.** Mass balance models showing large fluctuations in atmospheric gas composition and former soil respiration of the last 500 million

years can now be confirmed with isotopic data from Phanerozoic paleosols. The atmosphere is isotopically heavier with carbon in its carbon dioxide than biologically fractionated carbon dioxide respired by soils, which is preserved in soil carbonate. Isotopically heavy soil nodules are characteristic of greenhouse periods of high partial pressure of carbon dioxide, whereas isotopically light nodules form in periods of low carbon dioxide. In addition, former soil respiration can be gauged from the distance within the paleosol over which isotopically light soil carbon dioxide is mixed with isotopically heavy atmospheric carbon dioxide. Isotopic studies of Late Ordovician paleosols, some 440 million years old, have shown that they formed during a steamy greenhouse period (16–18 times present levels of atmospheric carbon dioxide). Furthermore, these paleosols had near-modern levels of soil respiration, which is surprising considering their lack of rooted or rhizomatous plants. Both paleosols and fossil spores in Ordovician rocks indicate primary producers on land no more complex than cyanobacteria, lichens, or liverworts. Late Ordovician paleosols and fluvial deposits contain burrows and trackways of millipedes. High respiration rates inferred from isotopic studies of Ordovician paleosols indicate an abundance of these and other consumers in soils. Late Ordovician communities on land were unusual in having a high ratio of consumption to production, and thus would have contributed to the atmospheric carbon dioxide greenhouse.

**Land plants.** A major biological innovation during the Early Silurian (435 million years ago) was the evolution of lignin, at first in slender vascular strands of early land plants, but by Middle Devonian time (380 million years ago) forming massive tree trunks. Lignin is physically durable and chemically resistant to decay, and so sequesters carbon from atmospheric carbon dioxide that fuels its photosynthetic production. Lignin also forms rigid plant endoskeletons, supporting enormous aboveground biomass, as well as copious underground supporting roots. The evolution of woody root traces can be seen from their progressively deeper and more profound bioturbation of paleosols of Silurian and Devonian age (Fig. 2b and e). Furthermore, the degree of weathering of essential mineral nutrients increased in paleosols over this span of time, as does the drawdown of atmospheric carbon dioxide evident from isotopic study of carbonate nodules in the same paleosols (Fig. 2a and c). The drawdown is already far advanced by Late Silurian time, well before the Middle Devonian appearance of trees and Late Devonian appearance of woody coals. Trees and coals were important carbon sinks during Carboniferous expansion of glaciation in the southern continents, but were preceded by the long-term atmospheric carbon dioxide consumption by soils and plants (Fig. 2d–f).

**Life crisis.** Abrupt global oxidation of carbon and greenhouse warming is now documented from car-

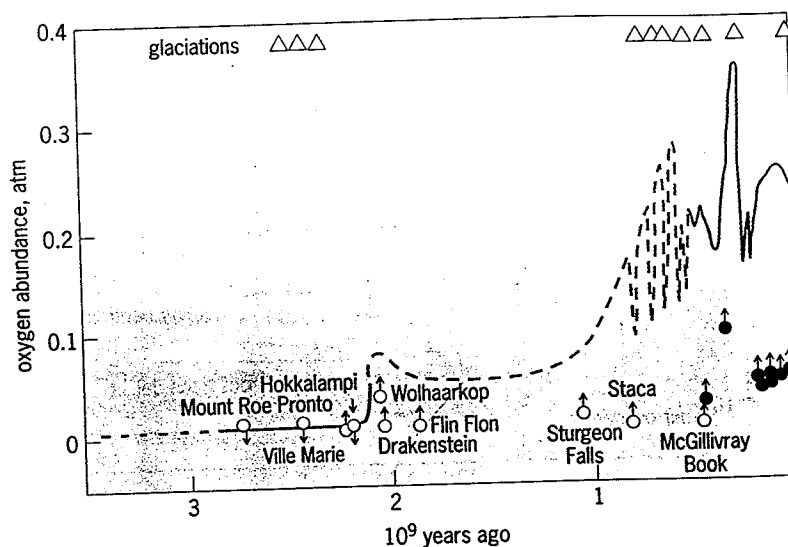
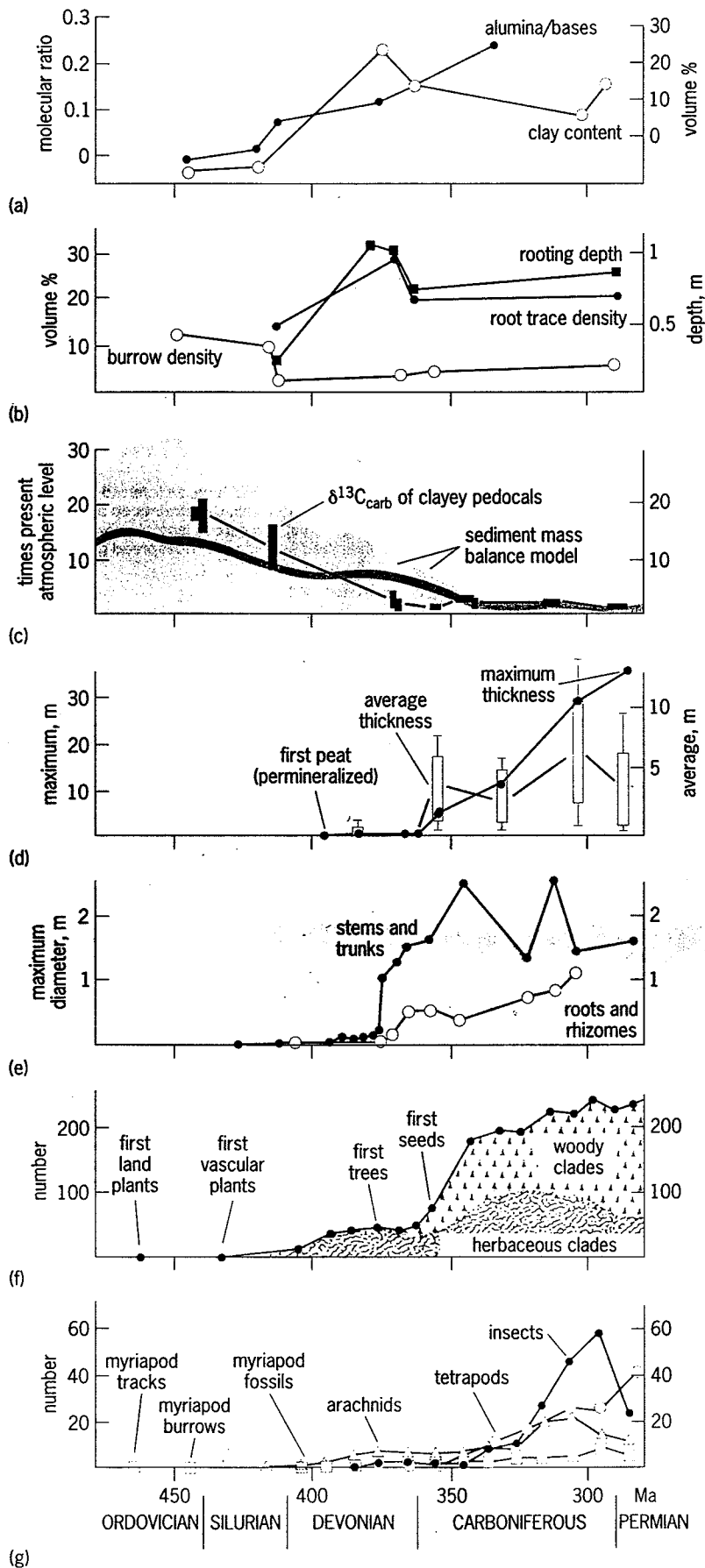


Fig. 1. Abundance of atmospheric oxygen through geological time, as inferred from the oxidation state and carbon isotopic composition of paleosols. Constraints on the curve come from redox chemistry of paleosols (open circles) and carbon isotopic composition of pedogenic goethites (solid circles). Also indicated are times of widespread glacial paleoclimate (triangles).

bon isotopic studies of paleosols and sediments across the Permian-Triassic boundary, some 250 million years ago, which was the most profound extinction event of geological time. A post-apocalyptic greenhouse also is reflected in earliest Triassic paleosols of Antarctica and Australia, which include deeply weathered soils (Ultisols) of kinds found now in warm climates of low latitudes and anomalous for paleolatitudes within the polar circle (Fig. 3). Extremely light carbon isotopic composition of organic matter in some of these paleosols is evidence that biogenic methane must have been a part of this earliest Triassic greenhouse. Antarctic and Australian south polar lowlands remained humid and had sedimentation rates that should have encouraged peat accumulation, yet no coals are found in Early Triassic rocks there or anywhere else in the world. Extinction of peat-forming plants at the end of the Permian is the best explanation for this global coal gap, just as extinctions of corals and bryozoans may explain the earliest Triassic reef gap in the marine fossil record.

**Dinosaurs.** The Jurassic Period of 146–208 million years ago was another time of greenhouse atmosphere. The carbon isotopic composition of pedogenic carbonate in formerly well-drained Jurassic paleosols is again heavy, and Jurassic paleosols of temperate (rather than frigid) paleoclimatic affinities are found at high paleolatitudes. Many of these red calcareous paleosols with large nests of termites and the bones of sauropod dinosaurs resemble soils of the semiarid seasonally dry tropics. Plant productivity of comparable modern soils is surprisingly low to support such biomass of insects and dinosaurs. Jurassic paleosols could thus have contributed to the atmospheric greenhouse by overconsumption of



plant production comparable to human overgrazing of marginal rangelands today.

**Angiosperms.** By Late Cretaceous time, weedy angiosperms are common in weakly developed paleosols worldwide. They also dominated mangrove and fresh-water tropical swamp vegetation. These new kinds of plants, with their unprecedented ability to recover from disturbance, coevolved with a suite of ornithischian low-browsing dinosaurs. Organic matter content and soil structure of Late Cretaceous paleosols, together with the lighter isotopic composition of their carbonate, indicate decline from the peak greenhouse of the Early Cretaceous and Late Jurassic. This trend was abruptly reversed by a post-apocalyptic greenhouse following impact of a large asteroid in Yucatan and extinction of the dinosaurs at the end of the Cretaceous some 65 million years ago. This greenhouse was short-lived, perhaps no more than 50,000 years, judging from the perturbation in carbon isotopic composition of organic matter in paleosol sequences. Another short-lived (less than 100,000 years) greenhouse spike at the end of the Paleocene some 55 million years ago is reflected in unusually deep weathering of paleosols in Wyoming and elsewhere in the world. Yet another greenhouse spike in the middle Miocene some 16 million years ago is reflected in deeply weathered paleosols at high paleolatitudes in Oregon, Germany, Japan, and Australia. These transient perturbations are variously blamed on meteorite impacts, methane clathrate release, and flood basalt eruptions.

**Grasses.** During the past 40 million years of the Cenozoic, a long-term trend of paleoclimatic cooling and drying into the ice ages of the past 2.5 million years is matched in the fossil record of soils by a spread of the finely rooted, organic-rich, crumb-structured soils of grasslands (Mollisols) [Fig. 4]. Coarsely granular paleosols with a dominance of fine root traces first appear some 33 million years ago, at the Eocene-Oligocene boundary, and represent the appearance of dry rangelands with bunch grasses, rather than only woody shrubs that dominated Eocene and earlier arid lands. Grass pollen and fruits become only a little more common in the fossil record

Fig. 2. Early Paleozoic changes in weathering, atmosphere, and evolution of plants and animals in eastern North America. (a) Soil differentiation is indicated by clay content (volume %) and alumina/bases (molecular ratio) of the most weathered horizon of calcareous red paleosols. (b) Soil bioturbation is indicated by proportion of line transect in paleosols occupied by roots or burrows (%) and by measured rooting depth (cm). (c) Atmospheric CO<sub>2</sub> levels (relative to present atmospheric level, or PAL) are calculated from a mass balance model (curve) and estimated from carbon isotopic composition of pedogenic nodules (solid boxes). (d) Maximum coal seam thickness and average thickness of at least 10 consecutive seams (meters). (e) Diameter of fossil plant stems and roots (meters). (f) Diversity of fossil plants, including both woody and herbaceous forms (number of species). (g) Diversity of soil animals (number of families). (Used with permission from G. J. Retallack, *Early forest soils and their role in Devonian global change*, *Science*, 276:583-585, 1997, and the American Association for the Advancement of Science)

at this time, and despite extinctions of some archaic browsing lineages, mammals show only modest evolutionary adaptations to grasslands in tooth and limb structure.

The advent of sod grasslands in the early Miocene (some 20 million years ago) was restricted to dry regions, because all these finely rooted, crumb-structured paleosols have carbonate nodules at shallow levels within their profiles as in soils of regions receiving less than 400 mm mean annual precipitation. At this time there is a major evolutionary radiation of mammals, such as horses in North America, notoungulates in South America, and antelope in Asia, with high-crowned teeth adapted to gritty graze and with cursorial limbs for sprinting in open vegetation. By late Miocene time (some 7 million years ago) finely rooted and crumb-structured paleosols of sod grasslands are for the first time found with calcareous nodules as deep as a meter. These paleosols signal the advent of tall sod grasslands, and the heavy carbon isotopic composition of their nodules indicates that this also was a time of increasingly widespread use of the C<sub>4</sub> photosynthetic system by grasses.

Alternations of grassland and woodland vegetation also can be documented on most continents through the glacial-interglacial paleoclimatic fluctuations of the Quaternary. Grassland soils could contribute to global cooling and drying in several ways. Their underground storage of carbon as organic matter is much more substantial than for desert scrub and woodlands of comparably dry climates. They also consume carbon dioxide as carbonic acid for weathering of silicate minerals within a crumb-structured soil that has a much higher internal surface area than soils of woodlands and deserts. The sod of grasslands also keeps the soil moister and the air above drier than soils of woody plants that actively desiccate the soil by root uptake and moisten the air with water vapor from transpiration of their leaves. Finally, grasslands have high albedo and are less absorptive of incoming solar radiation than dark and diffuse woody plants.



Fig. 3. This deeply weathered clayey paleosol (Ultisol) formed at a paleolatitude of at least 69°S during the Early Triassic in the Allan Hills, Antarctica. Such soils form today in warm climates, at latitudes no higher than 48°. The paleosol is thus evidence of high-latitude greenhouse paleoclimate.

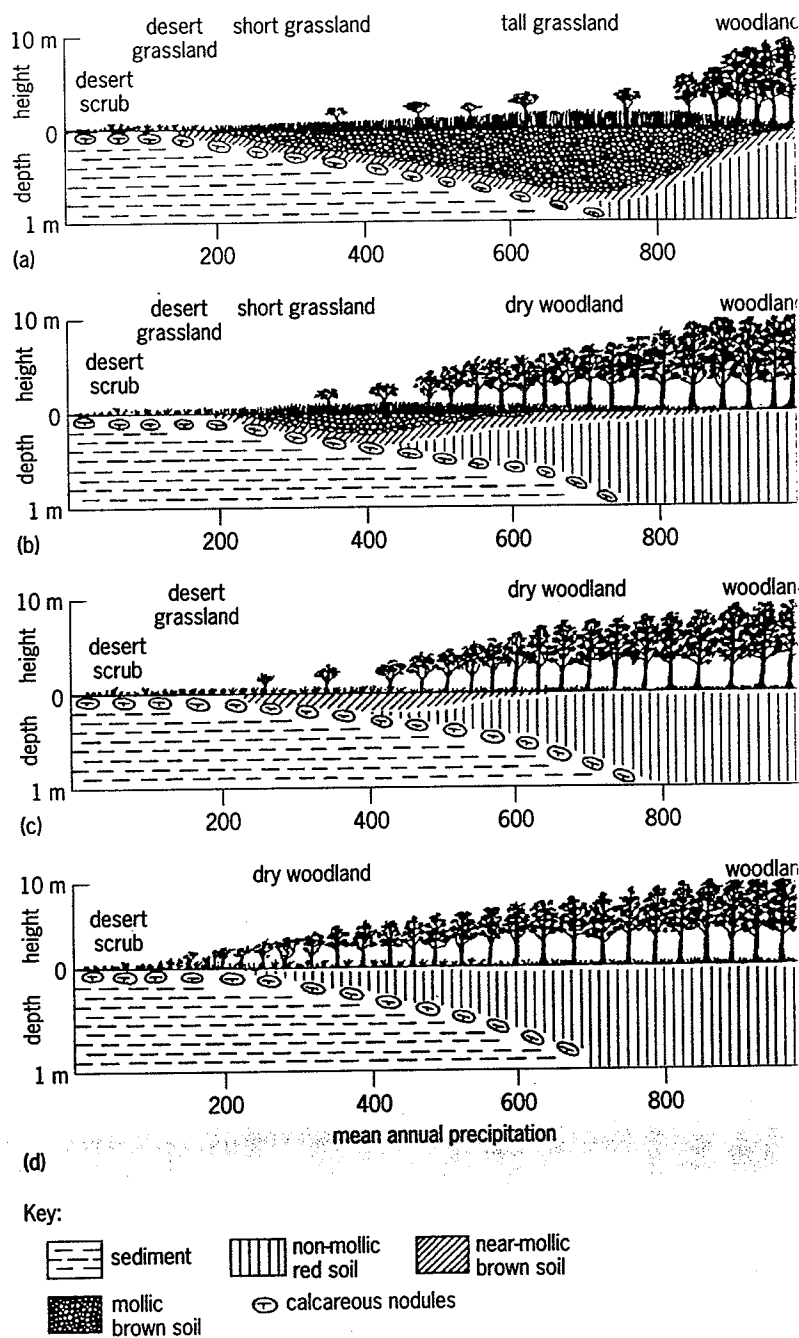


Fig. 4. Scenario for climatic and geographic expansion of grassland soils and their characteristic crumb-structured horizons in the North American Great Plains during the Cenozoic. (Used with permission from G. J. Retallack, *Neogene expansion of the North American Prairie*, *Palaos*, 12:380-383, 1997, and the Society for Sedimentary Research)

There is a long fossil record of soils, with major events linked intimately with those of terrestrial ecosystems that they supported. Soils are an important part of terrestrial ecosystems. Paleosols now are revealing that this was also the case in the geological past.

For background information see CARBON; CRETACEOUS; LIGNIN; PALEOCLIMATOLOGY; PALEOSOL in the McGraw-Hill Encyclopedia of Science & Technology. Gregory J. Retallack

Bibliography. G. J. Retallack, *A Colour Guide to Paleosols*, Wiley, Chichester, 1997; G. J. Retallack, *Soils of the Past*, Unwin Hyman, London, 1990; M. Thiry and R. Simon-Coinçon (eds.), *Palaeoweathering, Palaeosurfaces and Related Continental Deposits*, Blackwell, Oxford, 1999; M. Widdowson (ed.), *Paleosurfaces: Recognition, Reconstruction and Palaeoenvironmental Information*, Geological Society, London, 1999.

**Photogrammetry**

Particle tracking velocimetry (PTV) is a well-known technique for the determination of velocity vectors of flow within an observation volume. However, for a long time it was rarely applied because of the intensive effort necessary to measure coordinates of a large number of flow marker particles in many images. With today's imaging hardware in combination with the methods of digital image processing and digital photogrammetry, however, new possibilities have arisen for the design of completely automatic particle tracking velocimetry systems.

A powerful three-dimensional (3-D) particle tracking velocimetry system has been developed in a collaboration of the Institute of Geodesy and Photogrammetry with the Institute of Hydromechanics and Water Resources Management at the Swiss Federal Institute of Technology (ETH) Zürich. This system is currently capable of determining three-dimensional coordinate sets of some 1000 particles in a flow field at a time resolution of 30 or 60 data sets per second and a sequence length of about 2000 time steps. The system is fully automatic after initialization by an operator. A laser-induced fluorescence (LIF) system at the same location generates three-dimensional flow tomography data sets and tracking structures of interest through time and space.

**3-D PTV system.** Particle streaks, the time-exposed images of particles made visible by continuous illumination or pulsed illumination, have long been used for velocity measurements. Digital image analysis techniques opened the way for an automated

analysis of particle streak images. This technique, however, has some disadvantages. If applied to three-dimensional flows, it can bias the results toward small velocities. It is therefore preferable to use pulsed illumination and multiple-exposure techniques, and track the positions of individual particles recorded on a photographic or video frame.

**Hardware.** Two-dimensional particle tracking techniques, based on one camera, have been used in the past. By adding a second or even third and fourth camera, particle positions can be tracked in three-dimensional space. However, a new problem arises: the establishment of correspondences between images of individual particles in the frames of the different cameras. Three-dimensional particle tracking therefore involves three steps: the establishment of particle image correspondences, the determination of particle coordinates in three-dimensional space at a given time, and the tracking of the paths of individual particles in time. Once links between consecutive positions of particles are established, the velocity vector  $u$  is estimated from  $u = \Delta s / \Delta t$ , where  $\Delta s$  is the vector of particle displacement during the time increment  $\Delta t = f_c^{-1}$ ,  $f_c$  being the frame rate of the camera.

In the particle tracking velocimetry system at ETH Zürich mentioned above (Fig. 1), three or four off-the-shelf monochromatic charge-coupled-device (CCD) cameras are used with an image full-frame acquisition rate of 30 or 60 Hz. The volume of interest and the included particles in the medium are visualized by two halogen short-arc lamps with suitable reflectors. The optical axes of the cameras form angles close to 60°. The camera set can move with the average speed of the water flow. The cameras are synchronized by one master camera. The 8-bit images are produced in progressive scan mode at a size of 640 x 480 pixels. A maximum of two cameras can be controlled by one microcomputer, and the images are stored on a hard disk in real time.

**Calibration and data processing.** Since the imaging rays are reflected twice due to different refractive indices in the optical path through water, glass, and air, a fairly complex "multimedia sensor model" had to

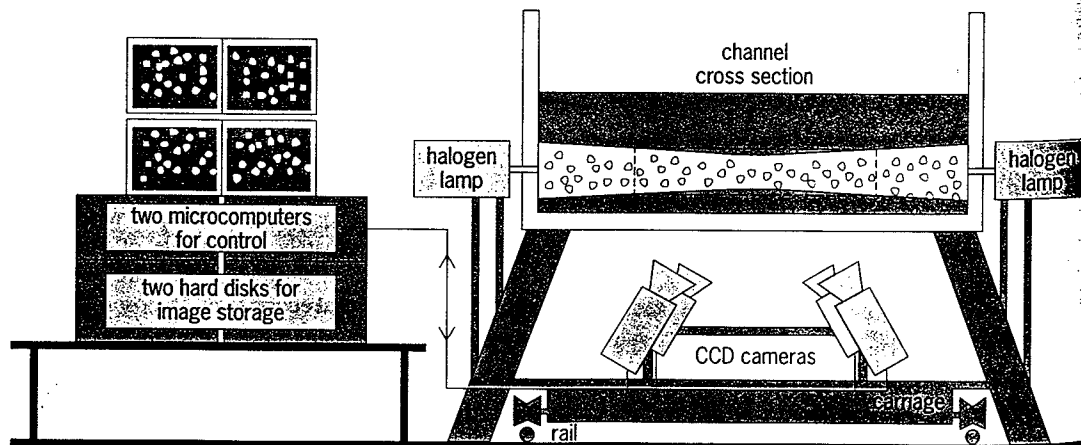


Fig. 1. Particle tracking velocimetry hardware installation for measuring flow velocities in a laboratory water channel.

digit  
pi

photog

objec

Fig. 2.  
trackin

be dev  
for the  
measu  
Bef  
calibr  
pose a  
vation  
image  
dimen  
well-d  
are kr  
accur

The  
forme  
entati  
16 pa  
entati

Fig. 3.

