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Climatic Ice Core Records from the Tropical Quelccaya Ice Cap

Abstract. *The Quelccaya Ice Cap in the easternmost glaciated mountain chain of the Peruvian Andes has been studied in four recent field seasons. Ice cores to a depth of 15 meters have been retrieved at the summit dome (elevation, 5650 meters) and two other locations and used for microparticle, isotope, and beta radioactivity measurements. A concurrent study of the present climate and the heat and mass budgets is being made to permit a paleoclimatic interpretation of deep core records. The results indicate the need for a revision of the isotope "thermometry" for application in the tropics. However, the seasonality of the beta radioactivity, microparticle content, and isotope ratios offers the prospect of a mass balance chronology. This is important in that precipitation is believed to be a more indicative paleoclimatic parameter than temperature in the tropics.*

During the last few years ice cores extending to bedrock have been obtained from the Greenland and Antarctic ice sheets and from other glaciers in high latitudes. Studies of these cores, especially of the ratios of the stable isotopes of oxygen and hydrogen and of the concentration of microparticles, have produced extraordinary records for the high latitudes (*1-9*). Assuming that the preliminary time scales are correct, synchroneity of temperature variations in the two polar caps is suggested by the oxygen isotope records on the time scale of millennia, although not on shorter time scales. The numerous paleoclimatic reconstructions for high latitudes contrast sharply with the information gap for the tropics. Therefore the possibility of applying the ice core paleoclimatic technique in the low latitudes merits particular attention.

Aside from logistic considerations, the following criteria guide the choice of an ice body for ice core and paleoclimatic studies. It is desirable to study an extended ice plateau of gentle topography so that effects of flow dynamics on stratigraphy are minimized. The ice cap should be at very high elevations and therefore low temperatures to preclude significant melting and percolation. Location in the outer tropics allows some seasonality in the stratigraphy. The thickness and net balance are limiting factors for the length of the climatic record to be expected.

Among the very few ice caps in the tropics are the North Wall Firn on Mount Jaya, Indonesia, and the Stanley Plateau in the Ruwenzoris, Uganda. However, both extend up to only about 4800 m and have relatively high air temperatures, so that melting and percolation are substantial. Because of its high elevation and low temperature, the Quelccaya Ice Cap in the easternmost glaciated mountain chain of the Peruvian Andes (Fig. 1) offers unique conditions for the retrieval of the first long ice core and climatic record in the tropics. The Quelccaya Ice Cap is located at 13°56′S, covers approximately 55 km^2, has a summit elevation of 5650 m, and lies on top of a gently undulating plateau of welded tuff. Along much of its margin the ice cap ends in vertical ice walls more than 50 m high that show marked banding.

The Ohio State University Institute of Polar Studies, in conjunction with the Instituto de Geología y Minería, Peru, has undertaken an extended investigation of this ice cap. The central objective of the glaciological program is the retrieval of a long ice core, from which a climatic history is to be reconstructed on the basis of isotope and microparticle analysis. Ice stratigraphy is intrinsically linked to current weather conditions and to the heat and mass budgets. Investigation of the present climate and determination of the heat and mass budgets of the ice cap are therefore prerequisites for climate reconstruction.

The major objectives of the first field season, in June and July 1974, included exploration of access routes and logistics and collection of snow samples (*7*). Expeditions in 1976, 1977, and 1978 excavated snow pits for density and temperature measurements; drilled 15-m cores for microparticle, β radioactivity, and isotope analyses; made measurements related to the heat and mass budgets; gauged streams; and emplaced net balance stakes. Automatic meteorological stations were installed on high fiber glass poles at the summit dome to record temperature, wind direction, wind speed, duration of sunshine, and precipitation. The glaciological program has been complemented by a study of the glacial geology (*10, 11*). The complete project history will be reported elsewhere (*12*).

Hourly temperature records have been obtained at Quelccaya summit from July to December 1976 and from July 1977 to May 1978. Daily mean temperature ranges from about −5°C in southern winter to −2° to −3°C in summer.

Budget estimates are sketchy for the ice cap as a whole but are most nearly adequate for the summit plateau, on which the ice coring effort is concentrated. From the characteristic vertical distribution of surface albedo and the empirically determined dependence of global radiation and net longwave radiation on cloudiness (*13*), it is possible to calculate representative monthly mean values of net all-wave radiation from the recorded duration of sunshine.

Some conclusions have been reached concerning the surface heat budget characteristics on the summit plateau. Clear-sky daily values of global radiation, upward-directed shortwave radiation, and net longwave radiation in July are of the order of 312, 250, and 52 W/m^2, respectively. That is, the net all-wave radiation is, for practical purposes and within the accuracy of the measurements, zero. This would also be true for other declination angles and varying degrees of cloudiness, because the cloud effect on shortwave and longwave radiation is largely compensatory.

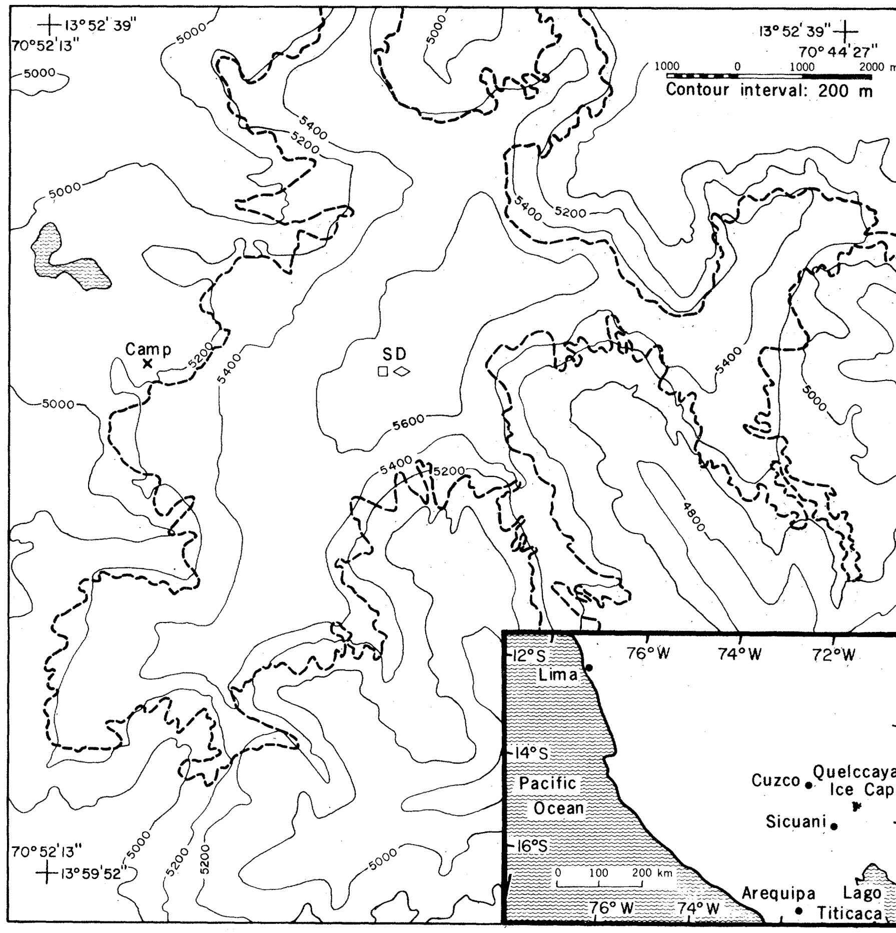
Accordingly, there is essentially no energy available for evaporation and melting. This has been confirmed by lysimeter measurements and bulk-aerodynamic estimates. Conditions similar to those at the summit prevail for a large part of the plateau above about 5400 m: ablation is essentially nil, and net balance approximately equals accumulation. At the Quelccaya summit net balance is of the order of 1 m/year (liquid water equivalent). The heat and mass budget characteristics at lower elevations on the ice cap are being reconstructed from measurements made during the expeditions.

During the 1976 field season the wall of a 3-m pit at the summit dome was sampled every 2.5 cm. In the bottom of this pit, two parallel cores were drilled 30 cm apart with a SIPRE hand auger to a depth of 12 m; the cores were thus altogether 15 m long. One core was used for microparticle measurements and the other for oxygen isotope and β radioactivity analyses. Oxygen isotope and β radioactivity analyses were performed at the Geophysical Isotope Laboratory in Denmark. Microparticle studies were conducted at Ohio State University under class 100 clean room conditions (*9*). A temperature profile established in the boreholes indicates that the Quelccaya Ice Cap is temperate (that is, the ice is at 0.0°C) at a depth of 15 m.

Figure 2 shows the microparticle profile in the two pits at the summit dome in 1977. In both pits large particle concentrations are found at the surface and at a depth of 2 m, corresponding to the June–July dry season. At this time of year snowfall is slight and solar radiation is intense, which favors the concentration of microparticles. The vertical profile of the coarseness factor indicates that particles falling during the December–May rainy season tend to be coarser than those deposited during the dry season, probably because of the deposition of local particles during the stormy rainy season. Annual variation is more pronounced for the small particles. Two closely spaced ice lenses were sampled at a depth of 1.64 to 1.68 m in the 1976–1977 accumulation in both pits. The ice lenses have a higher content of both small and total particles than the immediately adjacent snow layers, indicating that the particles were concentrated during lens formation. The results of preliminary analyses of pit samples in June 1978 are broadly consistent with the 1977 data.

Figure 3 shows the vertical distribution of small particles in the 15-m core, from a total of 183 samples; small particles are plotted because their seasonal variation is more distinct (see Fig. 2). Figure 3 illustrates 7 years of net balance, with major ice lenses and peaks in the particle concentration characterizing the dry season. Minor ice lenses and particle peaks occur at other instances during the year.

The vertical profiles and hence the annual variations of the oxygen isotope ratio (δ) and β radioactivity (Fig. 4) broadly parallel the microparticle profile. However, the least and most negative values of δ occur, respectively, in winter and summer snow. Although not the only exception (*14*), this is opposite to the seasonal variations commonly encountered at higher latitudes. Furthermore, the range of δ values at the surface, 22



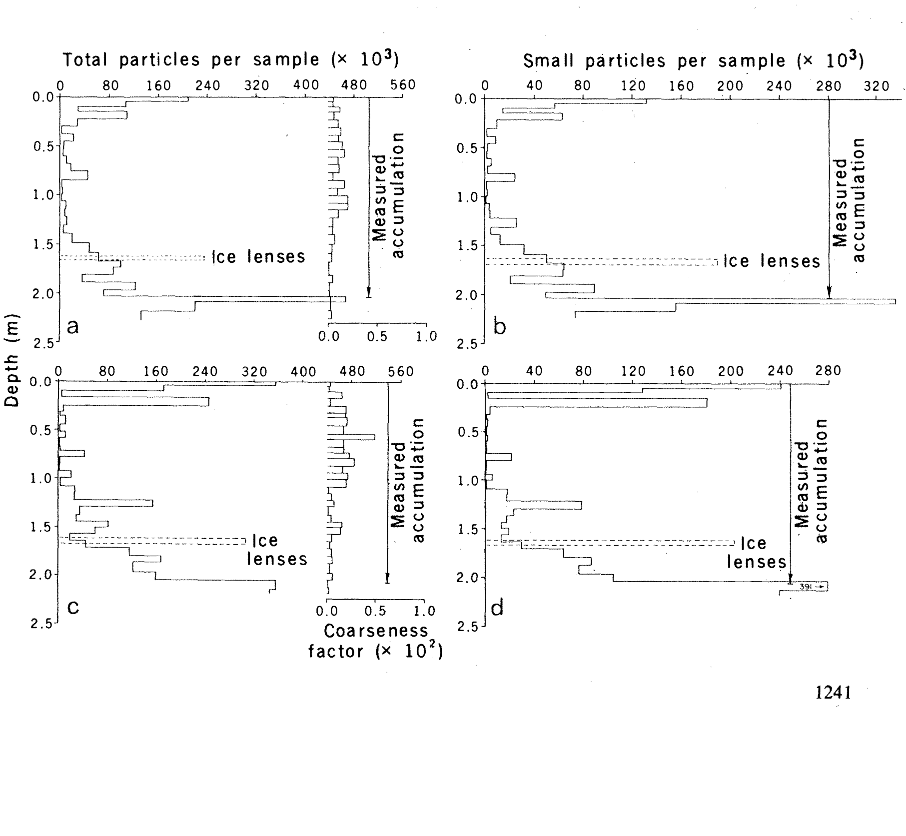
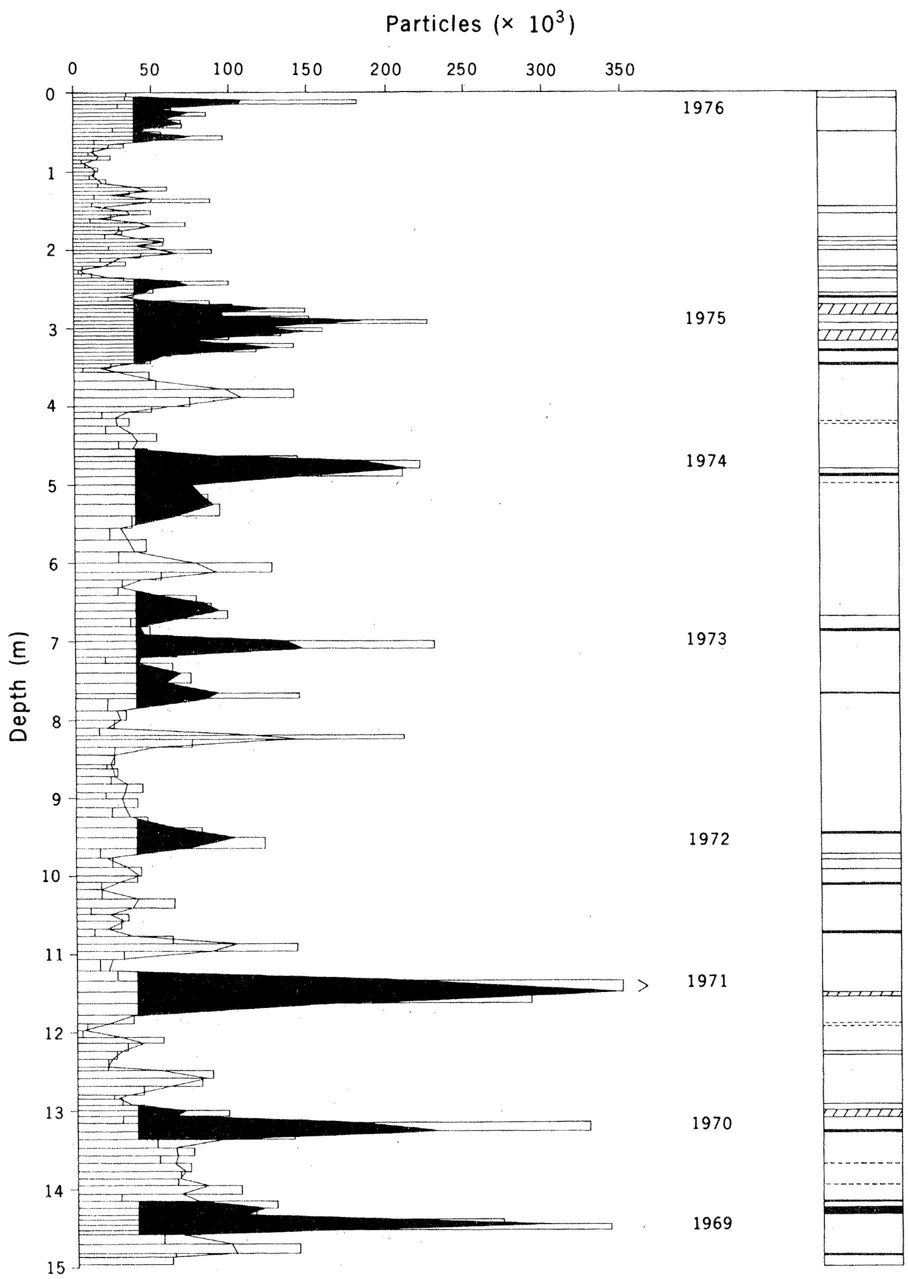


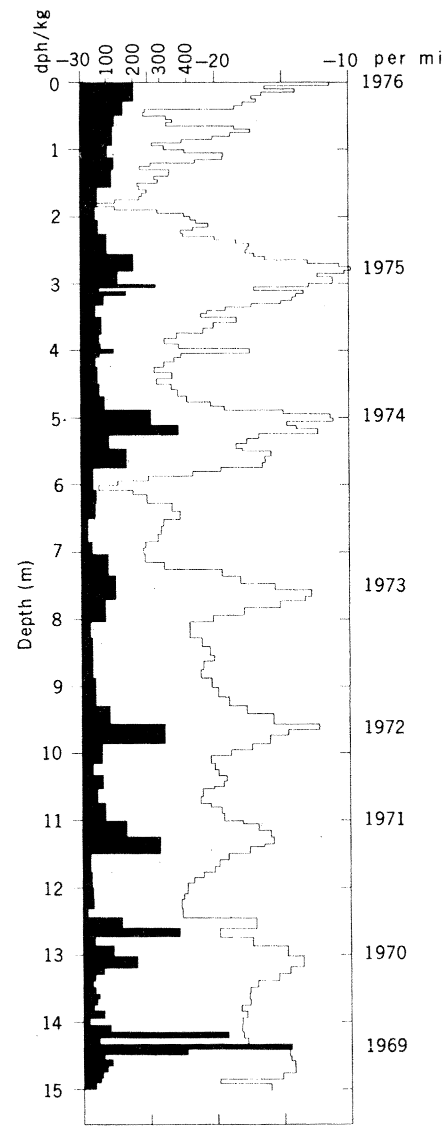
Fig. 1 (top). Map of the Quelccaya Ice Cap. The ice margin is indicated by a heavy dashed line, the weather station by a diamond, the snow pit and ice core site by a square on the summit dome (*SD*), and lakes and the Pacific Ocean by wavy lines. Fig. 2 (bottom). Vertical distribution of microparticle concentration in two snow pits (a and b; c and d) dug at the summit dome in 1977. (a and c) Variations of the total particle concentration; (b and d) variations of the small particle concentration (particles from 0.63 to 0.80 μm in diameter). The percentage coarseness factor is defined as 100 times the number of particles with diameters between 1.0 and 13.0 μm divided by the number of particles with diameters between 0.5 and 13.0 μm.

per mil, is greater than that reported for any other snow, firn, or ice core. The mean δ value at the surface, −21 per mil, is remarkably low for such a low-latitude site, where the mean annual air temperature is a few degrees below 0°C.

The few oxygen isotope measurements available for tropical snowfields show large variations. The δ values measured in fresh snow on the side of Kilimanjaro (3°S) ranged from −3.7 per mil at 4600 m to −6.8 per mil at 5700 m (*15*), and those measured at the Carstensz and Meren glaciers (4°S) of New Guinea ranged from −13.6 to −17.2 per mil, with a mean of −15 per mil (*16*).

From the coincidence of the peaks of particle concentration and β radioactivity and the fact that the least negative values of δ occur in the dry season (Figs. 3 and 4), one might infer a com-





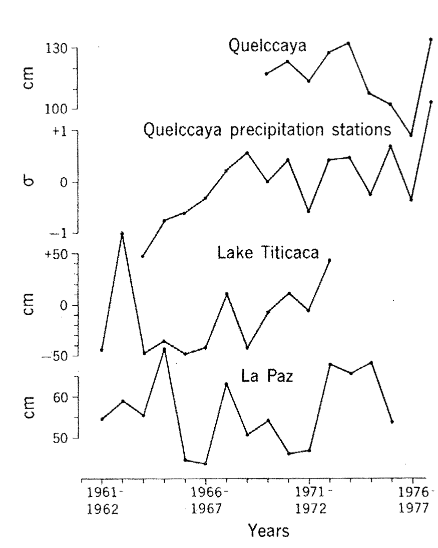


Fig. 3 (above left). Vertical distribution of microparticle concentrations (particles 0.62 to 0.80 μm in diameter) in firn and an ice core from the summit dome. The ice core stratigraphy is illustrated on the right; solid and dashed lines represent ice lenses and hatching represents visually dirtier layers. Dating of the profile is based on the June-July peaks of particle concentration and the coarseness profile. Fig. 4 (above right). (Shaded histogram) Variations in β radioactivity and (unshaded histogram) variations in the oxygen isotope ratio at Summit Dome. Fig. 5 (right). Annual values (July to June), expressed as liquid water equivalents, of net balance at Quelccaya summit, the water level change in Lake Titicaca; and precipitation at Observatorio San Calixto in La Paz. The precipitation index, in standard deviations (σ), was compiled from eight rainfall stations in the vicinity of Quelccaya.

mon source for β radioactivity and particles. In 1972, however, the seasonal peak of microparticle concentration was weak (Fig. 3), whereas that of β radioactivity was no less developed than in other years (Fig. 4). It is recalled that 1972 was an unusual year when the El Niño current extended along the coast of Peru; it was characterized by an anomalously high sea temperature, abundant rainfall, and low atmospheric pressure.

The extreme atmospheric and hydrospheric regimes of El Niño and their antithesis are tropical phenomena that can be identified from instrumental records for most of the 20th century (*13, 17, 18*) and from historical sources for the more distant past. It may be possible to ascertain from a deep ice core whether the variation in the seasonal microparticle peak at Quelccaya is characteristic of these large-scale circulation and climate anomalies.

From the data presented in Figs. 3 and 4 and the measured snow densities the annual net balance can be reconstructed back to 1969 (Fig. 5). When an ice core to bedrock is obtained it may be possible to extend this record back to A.D. 1500. In Fig. 5 the annual values of net balance are compared with an index of annual precipitation compiled from eight rainfall stations in the vicinity of Quelccaya. A positive correlation is apparent although the series are short. A further correlation is indicated with the annual changes in water level of Lake Titicaca and with precipitation at the Observatorio San Calixto in La Paz, Bolivia. Quelccaya net balance data from a deep ice core could be compared with Lake Titicaca water levels back to 1912, and this would allow us to relate the hydrometeorological changes on the Quelccaya Ice Cap to the regional climate.

Thus an attempt is being made to reconstruct a tropical climatic record on the basis of microparticle and isotope analyses of ice cores. Studies of the present climate and its relation to the microparticle and oxygen isotope variations in the current snowfall will allow a paleoclimatic interpretation of deep core records. The results to date indicate the need for a revision of isotope "thermometry" for application in the tropics. However, isotope thermometry will probably not be as important at low latitudes as it is in the polar regions, where annual and climatic temperature ranges are pronounced. At low latitudes the most useful paleoclimatic parameter is likely to be the variation in precipitation. The pronounced seasonality of β radioactivity, microparticle contents, and isotope ratios offers the prospect of a net balance chronology. The 8-year record of net balance obtained so far for the summit site parallels the hydrometeorological conditions in neighboring regions of the Andes. Both the Quelccaya net balance and the various hydrometeorological indices reflect control by the large-scale circulation rather than by local conditions. Retrieval in 1979 of a 100-m ice core and later of an ice core to bedrock may thus provide a key for the reconstruction of climate and circulation history in tropical South America in the recent past.

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L Amino Acids and D-Glucose Bind Stereospecifically to a Colloidal Clay

Abstract. *L-Leucine, L-aspartate, and D-glucose bind in a stereospecific manner to a colloidal clay, bentonite. This binding has high-affinity, saturable characteristics. The biologically uncommon enantiomers, D-leucine, D-asparatate, and L-glucose, do not exhibit any selective absorption on bentonite. It is suggested that this difference between stereoisomers could account for the evolution of life forms possessing a great preponderance of L amino acids and D-glucose.*

The reason for the occurrence of L rather than D amino acids as protein constituents is unclear. It may be that a random event early in biogenesis led to a preferential selection of L amino acids and this condition persisted throughout biological evolution. It was suggested (*1*) that an unknown process may have presented a slight advantage to L over D amino acids during early evolution. The concept that amino acid stereoisomers have a different susceptibility to decomposition by ionizing radiation has been investigated and disproved (*2*). The designation L amino acid implies that such compounds are stereochemically related to L-glyceraldehyde, rather than that they are levorotatory (*3*). While L and D amino acids are chemically identical, they may have different properties when covalently bound to or complexed with other molecules that are themselves chiral. In an analogous manner, D-glucose is found in a wide variety of organisms while L sugars occur much more rarely in nature. The evolution of this distinction has also been attributed to the stabilization of an event that was originally a random selection. Before the onset of life forms, the earth's primitive oceans may have contained low concentrations of organic molecules including amino acids, nucleotides, and sugars. These molecules have been experimentally formed from methane, ammonia, and water by using high temperature, ionizing radiation, light, and electric discharges to simulate prebiotic conditions (*4*). The stereoisomers of compounds formed in this way are present in similar amounts. If