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Session: Arid and Sub-arid Geomorphology

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## ARID AND SUB-ARID GEOMORPHOLOGY

Arid and sub-arid lands comprise about 30% of the Earth's surface. This is a zone of rapidly expanding human population and increasing pressure on natural resources, especially hydrological ones. For example, the American desert, once occupied by a sparse rural population, has become the seat of one of the most rapidly growing urbanized populations in less than 50 years. This pattern is being repeated in many other areas (e.g. Middle East, India, Latin America). Cities in these and other arid regions are prone to numerous geological hazards, including flooding by ephemeral runoff (flash floods), inundation by flooding of exoreic rivers, dust storms, sand encroachment, salt weathering of concrete structures, ground subsidence, and slope stability problems.

Geomorphologists working in such climatic zones have played and will continue to play a major role in understanding these hazards and seeking solutions to their mitigation. In addition, as populations in arid zones increase, there is much greater awareness of the unique nature of arid environments and their sensitivity to climate change and variability.

The sub-discipline of Arid Geomorphology has traditionally been poorly represented in the forefront of modern Process Geomorphology, but many new techniques and approaches have been applied first in this realm (e.g. optical dating of aeolian deposits, surface exposure dating). In this report we summarize some major developments in the field over the past several years.

### RECENT PROGRESS IN ARID AND SUB ARID GEOMORPHOLOGY

Geomorphic research in arid environments has attracted a wide variety of researchers who employ a range of techniques to understand modern processes and landscape evolution. A notable feature of much contemporary research is the collaboration between geomorphologists and those with specialized geochemical and geophysical knowledge, for example in the areas of exposure-age and luminescence dating. Carefully-conducted field experiments continue to provide new insights into the operation of geomorphic processes. Likewise, studies of landscape dynamics in the late Pleistocene and Holocene provide a much clearer picture of the response of geomorphic processes to climate change.

A significant development is the synergism between the search for solutions to environmental concerns and fundamental geomorphic research. For example, the need to understand landform development and the history of climate in the region of the proposed high-level nuclear waste storage facility at Yucca Mountain in southern Nevada has generated important fundamental research on soil forming processes, soil-landscape relations, slope stability, volcanic landforms, and evidence for past groundwater discharge conditions. Similarly, concerns about the response of sensitive semi-arid areas to possible future climate change has stimulated research into the Holocene climatic history and aeolian environments of the Great Plains and the Negev Desert.

### SLOPES AND RUNOFF PROCESSES

Many semi arid areas have experienced a change in

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vegetation from grassland-dominated to shrub-dominated systems over the past century. Although the causes of this change are still debated, its effect on ecosystems can be profound. Recently field experiments show that an increase in shrubs over grass leads to decreased resistance to overland flow, lower infiltration, and increased sediment yields. Increased runoff and erosion give rise to stripping of the soil A horizon, rill development, concentration of fine particles around shrubs, and armoring of the surface by desert pavement. On a longer time scale, climatic changes that affect vegetation and soil forming processes have a major effect on runoff generation and sediment yield, and may be responsible for periods of alluvial fan aggradation.

## AEOLIAN PROCESSES

Research into the mobilization, transport, and deposition of dust by wind is driven by the significance of particulates to air quality standards, land management and agricultural practices, and soil formation. There is an increasing emphasis on the quantification of rates of dust transport and deposition via field and modeling studies as well as the environmental variables (natural and anthropogenic) that control them. Dust deposition rates and the composition of aeolian dust in ocean sediments continue to be a valuable proxy index of desert conditions on adjacent landmasses and palaeowind directions. Studies of sand transport by wind have traditionally concentrated on wind tunnel experiments in which controlled conditions of airflow and sediment size have allowed precise quantification of relations between transport rates and boundary layer winds. Recent work is addressing more realistic conditions of unsteady flow and variable surface conditions so that geological and environmental problems can be addressed. Important aspects of surface conditions include moisture content, vegetation cover, slope, and surface roughness. Recent field studies have documented the spatial and temporal variability of actual transport rates in a variety of environments (beaches, simple dunes, agricultural lands, and playas). They provide valuable insights into the appropriate methodology and instrumentation to use (e.g. The effects of gustiness and turbulence on sediment transport are now being increasingly recognized and instrumentation to detect and measure them is becoming more widely available).

Studies of dune dynamics and airflow over bedforms are similarly beginning to recognize the limitations of traditional airflow models. Traditional paradigms (e.g. Two-dimensional compression of streamlines) and instrumentation (e.g. anemometer arrays) generally fail to identify and measure that part of the boundary layer that is responsible for sediment transport. Innovative approaches using direct measurements of sediment flux and hot-wire anemometry are beginning to provide new models for dune dynamics which emphasise the complex nature of interactions between sediment flux, boundary layer winds, and erosion

and deposition patterns on dunes. The complexity of lee-side flow has long been recognized, but new studies provide a revised view of the boundary layer in the lee of flow-transverse dunes.

Investigations at the dunefield and sand sea level are being revolutionized by new techniques, including luminescence dating and radiocarbon dating of organic materials in weakly developed soils, which are providing insights into the timing and duration of periods of dune formation and stability in the Mojave Desert the Great Plains, and Australia. On going studies of dune stratigraphy and age in the Arabian Peninsula, Tunisia, and southern Africa will help to resolve long-standing arguments about dune chronology and past environments, including wind regimes. Such developments will also enable testing of hypotheses regarding the development of spatial variability of dune patterns in sand seas (e.g. Closed lacustrine basins).

Most lakes in arid regions are hydrologically closed and provide important records of past and present climates and hydrologic conditions. Many of the large lake basins are fed by inflow from desert margin mountain and reflect climatic changes in these regions, pans (small closed lake or playa basins) are very widespread and numerous in low-relief arid regions in southern Africa, Australia, South America, and Australia and their morphology and sediments reflect local conditions. Lunette dunes are common on the downwind margins of many pans and their composition appears to be controlled in large part by local hydrology so that lunette composition may also be a valuable indicator of past hydrologic conditions. Dry lakes (Playas) are also very sensitive to anthropogenic impacts on water balance and contribute significant amounts of dust.

## SOILS AND LANDSCAPE EVOLUTION

Soil-landscape relations are widely used in desert areas to provide stratigraphic and relative age assessments of Quaternary deposits. The processes that control soil development are, however, very susceptible to the effects of climatic change, accumulation of aeolian dust, and lithologic control of parent material. The accumulation of dust also has a pronounced effects on infiltration capacity and soil-water balance that impact development of the vegetation cover and soil horizons. Desert pavements represent one of the most widely distributed arid landforms. Their formation has been attributed to a variety of processes including deflation, surface runoff and creep, and shrinking and swelling of soils that concentrate gravel-size clasts at the surface. An alternative hypothesis argues that the clasts remain continuously exposed at the surface as the pavement develops by deposition and modification of aeolian materials so that pavements are *born at the surface* and their characteristics represent a long record of the processes operating on this surface. Cosmogenic  $^3\text{He}$  surface-exposure dates for stone pavements on basaltic lava flows in the Mojave Desert show a high degree of internal consistency at each site with ages that are statistically indistinguishable from

the exposure age for the bedrock of the flow itself. These results indicate that the pavements were formed at the surface and support the accretionary model of pavement development. Gravel-free horizons underlying the surface can be used to distinguish this type of pavement from those formed by wind and water erosion. The *born at the surface* model of desert pavement formation is further supported by surface exposure dating of pavements and basalt flows in central Nevada using  $^{36}\text{Cl}$  and  $^{10}\text{Be}$  cosmogenic isotopes.

Although similar accretionary pavements occur on alluvial fans, transport of the clasts may result in inherited exposure and therefore some datings do not provide exposure ages that are consistent with the deposition and/or formation of the landform. Recent developments in the dating of soil carbonates may, however, provide a means to establish the age of alluvial fan units. Another approach is to use luminescence dating of interstratified aeolian or fluvial sand to constrain fan ages. Reliable dating of periods of alluvial fan accumulation is necessary to evaluate the relative role of climate versus tectonics in their formation.

## ARID GEOMORPHOLOGY AT BOLOGNA

The large number of papers (31) contributed to this session indicates the level of activity in Arid Geomorphology, as well as the diversity of approaches being used. The papers fall into four main groups: (a) long term landscape evolution of specific areas or regions (10 papers); (b) long term climatic change in nowadays arid regions of the globe (3 papers); (c) studies of process-form and process-sediment relationships (12 papers) and (d) monitoring and interpretations of ongoing desertification processes and other environmental problems of arid areas (6 papers).

All these four areas are equally important. We need to learn from the geological past what can be the long term products of geomorphic processes; how relic forms and materials may influence subsequent phenomena; how short term tendencies interact with trends and fluctuations of longer duration, etc. Then, we need process studies on small spatial and temporal scales with sophisticated instrumentation to quantify rates of processes, understand the role of each contributing factor and develop models and formulas. The monitoring (both remote and field based) of current processes and change, while contributing precious data to the investigation of arid landscapes dynamics, is of paramount importance to optimise the delicate relationships between Man and arid environments.

Papers of the first group included studies regarding areas of Jordan, Israel, Iran, Niger, Angola, South Africa, Argentina, and China. All these papers give interesting data about the origin of the present landscapes of the study areas. Those by A. Cinque & *alii*, on pediments and terraces of the Atlantic slope of Angola, and by Z. Liu & *alii*, on the fluctuation of the Qaidam Basin lakes (Western China), also point out the need to filter the changes due to neotectonics from those due to climate change.

The second group included an interesting paper by R. Baumhauer & P. Felix-Henningsen documenting the climatic change occurred in the Central Sahara since the end part of Late Pleistocene and a paper by Mahmoud A.A. on the impact of Holocene climatic change on the history of human settlement in the Egyptian Western Desert.

A good example of process studies is the paper by K.C. Anderson & S.G. Wells on the development of accretionary desert pavement in the Mojave Desert of California. Comparable examples are the papers by A. Goudie & H. Viles on the rates of salt weathering of rock blocks in the Namib Desert, by D. Jakel on the mechanisms controlling the origin of «Kessel» and network dunes in the Gobi desert, by N. Lancaster on the influence of vegetation on aeolian entrainment and transport of sand, by A. Parson on laboratory experiments about sediment transport competence of inter-rill overland flow and by V.S. Zaletaev on the role of vegetation and animals in the morphodynamics of Central Asia arid and sub-arid zones.

Within the fourth group V.P. Tchakerian & *alii*, presented a study aimed to understand the cycling of fine sediments through the Wahiba Erg of Oman, based on analyses of terrestrial and aerosol samples. Other two interesting papers were presented by A. Ozer & P.J. Ozer and by J.B. Ries; the first one regarding the remote sensing of 30 years of desertification and geomorphological change in an area of Southern Niger, while the second one concerning an area of the Ebro Basin (Spain) that was monitored by large scale photography taken from a hot air blimp.

## CONCLUSION

In general terms, it is to be observed that many years of speculation on the formative processes of arid and sub-arid landforms have been replaced by studies aimed to gain quantitative information and new process-response models. One recurring theme is that of process-linkages. For example, vegetation cover, although sparse in most deserts, has been shown to have important relations to surface processes, including sand transport by wind, runoff and sediment mobility on slopes. On longer time scales, soil and desert pavement formation can be shown to have a major impact on the development of desert vegetation cover. Modern research is showing clearly that there are many interactions also between fluvial and aeolian processes in drylands. Aeolian accumulation patterns in time and space are strongly controlled by sediment supply from fluvial sources. Aeolian dust deposition has significant impact on slope processes, soil development and runoff-infiltration relations, which in turn affect sediment supply to fluvial systems.

Climate change and variability are major influences on arid lands geomorphic systems. Periods of alluvial fan aggradation and degradation appear to be controlled by climatically-influenced variations in the availability of sediment relative to available stream power, modulated by veg-

etation cover and hillslope runoff processes. Cut and fill sequences in arid rivers may also in part be the product of climate change. The long term dynamics of many dune systems are determined by changes in wind energy and sediment mobility (especially the degree of vegetation cover), as well as by changes in sediment supply from fluvial systems. The characteristics of playas and dry lake systems are controlled in large part by regional changes in the hydrologic balance. The large effect of Holocene climatic changes on geomorphic systems are good indications of the degree of change possible in modern climatic and geomor-

phic systems, and have clear implications for the future of arid lands.

Although great progress in understanding the dynamics of arid lands geomorphic systems has been made in recent years, many opportunities and challenges for innovative and imaginative research in drylands still remain. Neglected environments and processes include playa systems (which are important sources of aeolian dust, as well as good indicators of hydrologic regimes) and pediments (major sources of runoff and efficient transmitters of detrital materials).