LOSE LOSS-BRIEFE

LOESS LETTER 34

OCTOBER 1995 ISSN 0110-7658

FRAGIPANS in LOESS

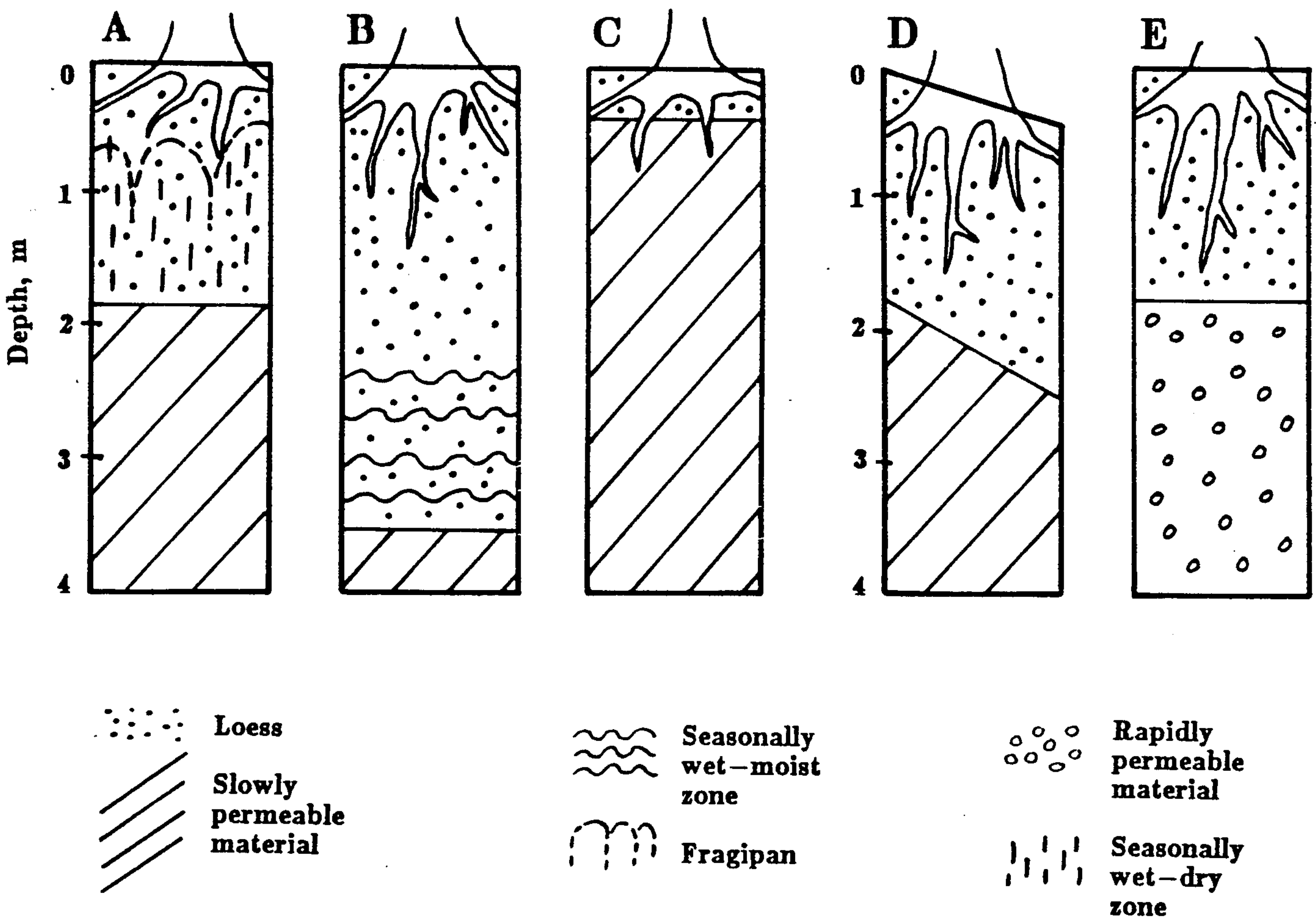


Fig. 5-6. Diagrams illustrating the factors that relate to fragipan formation. (A) Fragipan forms in loess where soil-water content above a slowly permeable zone fluctuates greatly because tree roots extract much water. (B) Fragipan does not form because saturated zone is too deep to be dried out by tree roots. (C) Fragipan does not form because loess is too shallow and the lower impermeable material contains too much clay. (D) Fragipan does not form because soil water moves downslope rapidly, on or in the soil. (E) Fragipan does not form because water moves down the profile too rapidly.

Samuel Finley Breese Morse
1791-1872

Inventor of Morse Code

LL34: October 1995

LL34 is the 'Fragipans in Loess' issue; it's a special issue for a whole variety of reasons. It's dated October 1995 but the plan is to publish early in the year, in time in fact for distribution at 14th INQUA in Berlin in early August. LL34 is a belated review and appreciation of the book 'Fragipans: Their Occurrence, Classification, and Genesis' edited by N.E. Smeck and E.J. Ciolkosz, and published as Special Publication 24 of the Soil Science Society of America, in 1989. We appreciate that fragipans are not exclusive to loess and do seem to form in other materials, but there is no doubt that loess and fragipans do go together, there is a relationship (as in loess and chernozems) so that it makes sense for the loess people to look at fragipans.

It is about 25 years since Guy Smith coined the term 'fragipan' so we have a quarter of a century of thought and investigation to look back on and to consider. And it might be worth considering the problem of fragipan formation in a Quaternary context, as a problem relevant to the INQUA Loess Commission. Smeck and Ciolosz, in their preface, make two very pertinent points; that fragipans are perhaps more investigated than any other soils phenomenon, and that we still do not know how they form. The debate could perhaps be widened, maybe this soil science problem needs more attention from outside soil science, maybe the civil engineers and geomorphologists and other Quaternary scientists could provide a useful input.

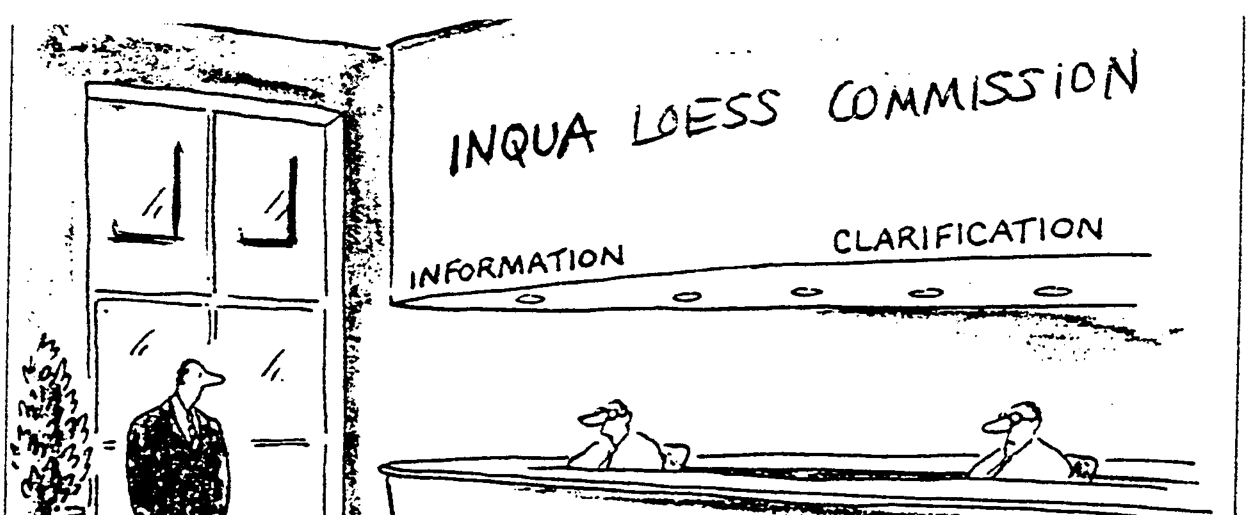
One of the most striking observations in Spec.Publ. 24 is that by R.B. Bryant in his paper on physical processes of formation. He relates fragipan formation to the collapse process occurring when loess soils suffer from hydroconsolidation. The soil engineers have laboured for many years on the problems caused by the collapse of loess when it is loaded and wetted. This causes great damage in all sorts of construction situations. In hydroconsolidation the open initial loess structure collapses to form a much more closely packed structure, and the process seems to depend on the presence of a small critical amount of clay mineral material. This has been extensively reviewed by Rogers et al. (Eng.Geol. 37, 83-113, 1994) and the attention of soil scientists is directed to this paper. Bryant cites a few useful hydrocon. references, and we are impressed that he has made the connection.

The INQUA Loess Commission has been operating since 1969 and initially focussed on the stratigraphy and dating of loess. Over the years the focus has changed and it will be proposed at 1995 INQUA that the research efforts be concentrated on loess material.
Dr. B. Smith of Queens University Belfast made a good case for this in the discussions held at the International Geomorphology Conference in Hamilton, Ontario in 1993 and it is proposed that this might become Loess Commission policy. The INQUA executive is proposing that the Commission structure be re-organised, and as part of this re-organisation, the Loess Commission may shift its focus to loess - the material. Loess stratigraphy can perhaps be better dealt with in the Stratigraphy Commission. Which brings us back to fragipans. Are they due to packing changes (like hydrocon.) or are they due to clay movement or solute movement, or how do these factors combine? These are interesting material problems and the 'fragipan in loess' problem can provide a useful focus to bring together soil scientists, engineers, geologists, etc. to work on a difficult (25 years old) problem.

LL34 contains a message to soil scientists: join in the activities of the Loess Commission, we share many interests. Together we will elucidate and clarify fragipan formation (and chernozemization - also best studied in a loess setting). and move the Loess Commission to a more firmly-based materials future. The hydrocon. problem is still dogging our footsteps - this will be further discussed at 14th INQUA, probably in Symposium 19 - this is 'Geotechnical Aspects of Quaternary Soft Rocks' organised by Dr. D. van Husen. Remember that Symposia 54, 55 and 56 are the Loess Symposia: 54 - Pleistocene Loess and Palaeoclimates, 55 - Reconstruction and Climatic Implications of Quaternary Palaeosols and Palaeosol Sequences, and 56 - Loess in Europe (in memory of Rudolf Grahmann). In S.56 we will discuss the status of the Loess Map of Europe, which Julius Fink initiated and which should be completed and published.

Back to fragipans. Spec.Publ. 24 contains eight excellent papers, plus preface and summary by Smeck and Ciolkosz. We can give you a taste of this by reproducing all the title pages and the preface and summary. The cover picture (of LL34) comes from the paper by Franzmeier, Norton & Steinhardt - in fact they supply all the illustrations which appear at random positions. Some criticisms of Spec.Publ. 24? Well it is very American, it would have been nice to have a chapter by a European. Worldwide occurrence needs to be mapped and studied; there is going to be a geographical input into the fragipan problem and we need to recognize as many sites as possible. The fragipans in the Port Hills loess in the South Island of New Zealand are the direct cause of the tunnel-gully erosion that occurs in that region - some of these practical problems could perhaps have been given more attention. But by and large, Spec.Publ. 24 is an admirable publication, it serves as another review of the fragipan situation. When Winters and Simonson reviewed fragipans in 1951 only 3 pages were required; when Grossman and Carlisle did their pivotal review in Adv.Agron. in 1969 they needed 42 pages: Smalley & Davin in 1982 covered 122 pages and now (in 1989) Smeck and Ciolkosz have assembled another 153; the data pile is growing.

To redress the geographical balance slightly we have added two European items to LL34: a study by R.W. Payton of the fragipans in the Millfield Plain, brought to us by courtesey of the CAB Abstracts Service, which itself reaches us via the kind agency of 'Dialog'. The various databases that are available via Dialog do allow a good overview of progress in fragipan investigation, but what we need are more bibliographies. Bibliographic activity is so useful - but so undervalued that little gets done; we need reviews and bibliographies but they do not get published. The GeoBooks bibliography series is long abandoned and the NZ Soil Bureau Bibliographical Report Series which gave us the Smalley-Davin fragipan study has disappeared along with the NZ Soil Bureau (and the whole of DSIR). The SSSA Special Report series does a good job of encapsulating areas of interest, and must be supported. Contact address: Soil Science Society of America, 677 South Segoe Road, Madison, Wisconsin 53711 - 1086, USA. Twenty-six Special Publications still available; we like the look of No. 26 on accumulations in soils, and No. 15 on micromorphology and classification. We still use our No. 5 Field Soil Water Regime, but notice that it has disappeared from the list. If you fancy your own copy of No. 24, send $24.00 (+ 10% postage) to SSSA, or send them your credit card number.



Loess Letter is the newsletter of the Loess Commission of INQUA - the International Union for Quaternary Research (originally Internationale Quartärvereinigung). It is published twice a year, nominally in April and October, but on special occasions, such as the INQUA Congress Year (like 1995) the schedule is adjusted. We aim to circulate LL33 (the QI special) and LL34 (the Fragipan special) at the Berlin August meeting. The Loess Commission officers are:

President:	Professor An Zhi-sheng Xian Laboratory for Loess Research P O Box 17, Xian 710061, P R China fax: +86.29.5262566
Vice-President:	Professor N. Fedoroff Lab. de Science des Sols INAPG, 78850 Thiveral, France fax: +33.1.305.49454
Secretary: (& LL Editor)	Professor Ian Smalley Centre for Loess Research & Documentation Leicester University, Leicester LE1 7RH, UK fax: 0116.252.3854

Send loess news and loess information to the editor at Leicester. We need some input about the future of the Loess Commission (and the future of LL). If there is to be a widespread revision of the commission structure at Berlin INQUA it would be useful if we could have some ideas to consider; contact any of the officers. There is one sad note in LL34; Wang Jing-tai of the Geological Hazards Institute in Lanzhou died on 24 November 1994. His obituary in 'The Independent' was by Edward Derbyshire, secretary of INQUA; we reproduce it here.

Fragipans: Their Occurrence, Classification, and Genesis

Proceedings of a symposium sponsored by Divisions S-5 and S-9 of the Soil Science Society of America in Atlanta, GA, 1 Dec. 1987.

Editors
Neil E. Smeck and Edward J. Ciolkosz

1989

1 Identification, Role in Soil Taxonomy, and Worldwide Distribution of Fragipans
J.E. Witty and E.G. Knox 1

2 Fragipans in the Northeastern United States
D.L. Lindbo and P.L.M. Veneman 11

3 Occurrence and Characteristics of Fragipans on the Coastal Plains of the Southeastern United States
B.R. Smith and R.B. Daniels 33

4 Fragipan Distribution in the South Central States
W.H. Hudnall and D. Williams 43

5 Fragipan Formation in Loess of the Midwestern United States
D.P. Franzmeier, L.D. Norton, and G.C. Steinhardt 69

6 Weathering Discontinuities: A Key to Fragipan Formation
Neil E. Smeck, M.L. Thompson, L.D. Norton, and M.J. Shipitalo 99

7 Solution Chemistry of Fragipans—Thermodynamic Approach to Understanding Fragipan Formation
A.D. Karathanasis 113

8 Physical Processes of Fragipan Formation
R.B. Bryant 141

9 Summary
Neil E. Smeck and Edward J. Ciolkosz 151

SSSA Special Publication Number 24

Soil Science Society of America, Inc.
Madison, Wisconsin, USA

PREFACE

Fragipans are very important pedological features that occur in Europe, New Zealand, the USA, and other parts of the world. From an agricultural perspective, fragipans are undesirable because they restrict rooting depth and retard removal of excess water that results in decreased productivity. Nonagricultural uses of soils with fragipans are primarily impacted by restricted water percolation through the soil. Thus, uses such as on-site waste water disposal are limited or, in many cases, impractical.

As a result of their extent and importance, fragipans have intrigued pedologists for more than 50 yr. It is probable that more papers have been presented and manuscripts published on fragipans than any other soil feature. Most pedologists have at one time or another studied fragipans. A sample listing of prominent pedologists who have published manuscripts involving fragipans follows: Arnold, Bailey, Bartelli, Beavers, Bruce, Carlisle, Cline, Daniels, DeConinck, DeKimpe, Fanning, Fitzpatrick, Fehrenbacher, Franzmeier, Gamble, Gile, Grossman, Hole, Holowaychuk, Knox, Langohr, Leamy, McCracken, McCormick, McKeague, Miller, Nettleton, Ruhe, Simonson, Smalley, Smith, Travernier, White, Whiteside, and Wilding. Despite all of this effort, the mechanism of fragipan formation is still uncertain, and the identification of a fragipan is subject to considerable individual interpretation. The identification of fragipans is currently envisioned as a field problem involving a combination of clues because there is no single unique property that defines a fragipan. Some of the clues concern the presence of a polygonal pattern, root restriction, brittleness, and slaking in water. Genetically fragipans are just as intriguing; some pedologists contend that they are primarily a physical phenomenon, others contend that they are a result of chemical bonding.

The objective of the symposium at the 1987 meetings of the Soil Science Society of America, which gave rise to this publication, was to update information on fragipans by emphasizing the most recent investigations and innovative approaches to the study of fragipans. Contributions from Europe and four regions of the USA were included in the symposium; unfortunately, a manuscript for the former was not provided for inclusion in this publication. Although an attempt was made to include all genetic viewpoints, it was not possible to obtain the participation of scientists favoring some hypotheses. It was not the intent of this symposium to provide a comprehensive understanding of the genesis of fragipans nor unanimous agreement on a theory for fragipan formation. The goal was to provide an update of the state of knowledge regrading fragipans in order to provide a starting point for future work. Ideally this publication will point out the need for and direction of future scientific inquiry that will foster rapid advancement in our understanding of fragipans.

Editors

Neil E. Smeck, *The Ohio State University, Columbus, Ohio*

Edward J. Ciolkosz, *The Pennsylvania State University, University Park, Pennsylvania*

1 Identification, Role in Soil Taxonomy, and Worldwide Distribution of Fragipans[1]

J. E. Witty and E. G. Knox
USDA-SCS
Washington, DC

ABSTRACT

The fragipan is identified in *Soil Taxonomy* as a genetic soil horizon. It is a diagnostic subsurface horizon that restricts the penetration of roots and water. The definition has not facilitated consistent recognition of fragipans. Major identification problems are determination of pedogenic origin and verification of the required brittleness. Interpretations for use of soils with a dense layer that limits roots and water do not depend on origin. The fragipan is used as a criterion for great groups in the Alfisol, Inceptisol, Spodosol, and Ultisol orders. Soils with fragipan are dominantly in mid-latitudes in medium-textured, acidic glacial drift, loess, colluvium, lacustrine materials, or alluvium. They most commonly have a udic or aquic moisture regime. They have been mapped primarily in the USA and New Zealand. Small-scale maps underestimate their extent in other countries where they may occur. A better definition is needed for consistent recognition.

The term *fragipan* was coined in 1946 by Guy D. Smith (Grossman & Carlisle, 1969) to identify one type of pan in soils classified in the USA at that time as Planosols (Smith, 1986, p. 76). It is generally acknowledged that fragipans are important for interpretation of soil use. In spite of the large number of theses, special studies, and papers about fragipans, the concept does not seem to be well understood (Smalley & Davin, 1982; Smith, 1986, p. 76). The definition of the fragipan, which Guy D. Smith (1986, p.76) characterized as being "completely inadequate," and doubts and questions about the origin of fragipans have made positive identification in the field difficult. Consequently, there is little information available about worldwide distribution of soils with a fragipan.

[1] Contribution from the Soil Survey Division, USDA-SCS, P.O. Box 2890, Washington, DC 20013.

 Fragipans: Their Occurrence, Classification, and Genesis, SSSA Special Publication no. 24.

2 Fragipans in the Northeastern United States[1]

D. L. Lindbo and P. L. M. Veneman

University of Massachusetts
Amherst, Massachusetts

ABSTRACT

This chapter summarizes 40 yr of research on fragipan morphology, formation, and classification conducted in the northeastern region of the USA. Fragipans occur in 13% of the soils in the region and have often been observed to exert a distinct influence on the hydrology, morphology, and land use. Fragipans in the southern part of the region have developed in transported materials such as colluvium, alluvium, terraces, lacustrine, and coastal plain sediments, while in the northern part most have formed in glacial till. The most northern areas of the region consist largely of dense basal tills, which do not appear to have been pedogenically altered. Although classified as fragipans formerly, most of these northern-most soils now are considered non-fragipans. In the southern part of the glaciated area, on the other hand, the basal tills do exhibit sufficient fragic character to be considered a fragipan. Most fragipans in the Northeast have bleached prism faces, especially those in moderately well to somewhat poorly drained soils. They exhibit high and low chroma mottling, clay coatings, vesicular pores, and massive to platy structure. These horizons exhibit high bulk densities, ranging from 1.65 to 2.15 Mg m^{-3}, with the pans developed in till generally at the upper end of the range. Densities of the horizons above and below commonly are lower. Brittleness and the ability to slake in water are common features associated with all fragipans, including those developed in glacial till. Research indicates that these characteristics are, to a large extent, due to bonding by clays forming bridges between soil particle and aggregates. Iron, aluminum, and silica may also contribute to the fragic properties of these deposits, especially in the nonglaciated areas. Our review indicated that there is no unifying theory as to how fragipans form. Most likely, several polygenetic modes of formation give rise to the same type of soil horizon. There is a need to more clearly define fragipan diagnostic criteria to allow for a better separation between fragipans and fragipan-like materials.

The fragipan soils of the northeastern USA have been studied extensively during the last 40 yr (Grossman & Carlisle, 1969; Smalley & Davin, 1982). The term *fragipan* was first used by Winters in the early 1940s to refer to

[1] Contribution of the Massachusetts Agric. Exp. Stn., Article no. 2869, Univ. of Massachusetts, Amherst, MA 01003.

3

Occurrence and Characteristics of Fragipans on the Coastal Plains of the Southeastern United States[1]

B. R. Smith

Clemson University
Clemson, South Carolina

R. B. Daniels

North Carolina State University
Raleigh, North Carolina

ABSTRACT

Fragipans in soils on the Coastal Plains of the Southeast have been reported by several investigators, but there has been some disagreement about the extent of these soils. Approximately 190 000 ha are now correlated as of 1988 as having fragipans, and most of these soils (178 000 ha) are in the Southern Coastal Plains Major Land Resource Area (MLRA). The remainder occur in the Atlantic Coast Flatwoods MLRA. Most of the soils with fragipans on the Coastal Plains are in fine-loamy families, not silty families. Few of the fragipans have polyhedrons or prisms with roughly vertical, bleached faces normally associated with fragipan horizons. Fragipans have been reported in North Carolina in lower eluvial horizons of bisequal soils that are rather poorly drained. In other areas, fragipans have been observed immediately below argillic horizons in well-drained soils. The presence of plinthite in some soils with fragipan horizons is a feature unique to the Coastal Plains in the USA. Recent studies have indicated that some horizons previously designated as fragipans in soils on the Coastal Plains did not meet all of the criteria of fragipans. As a consequence of these studies, 500 000 ha of soils have been reclassified from Fragiudults to Hapludults. In most instances, these horizons have brittle matrix that constitutes <60% of the volume, although they contain substantial amounts of brittle material. These horizons in soils on the Coastal Plains have most of the properties of fragipans and certainly affect root growth and water movement. The establishment of Fragic subgroups is proposed for these soils.

[1]Technical contribution no. 2818 of the South Carolina Agric. Exp. Stn., Clemson Univ., Clemson, SC 29631.

4

Fragipan Distribution in the South Central States[1]

W. H. Hudnall

Louisiana State University Agricultural Center
Baton Rouge, Louisiana

D. Williams

USDA-SCS
Fort Worth, Texas

ABSTRACT

The distribution of fragipan soils according to areal extent, Major Land Resource Areas (MLRAs), parent materials, and classification is presented for the six south central states of Arkansas, Louisiana, Mississippi, Oklahoma, Tennessee, and Texas. The Map Unit Use File (MUUF) was used as the major data base for information in this study. This data base contains information at the county level, such as acreage and phase information. These data are entered when the correlation of the county soil map is completed. Only the counties that have been mapped and correlated are included in this study. There are 62 series comprising about 4.40 Mha that are mapped in 200 counties. In Arkansas, 25 fragipan soil series have been mapped in 60 counties. These soils represent 1.75 Mha or about 16.4% of the acreage in these 60 counties. Louisiana has mapped 21 fragipan series in 27 parishes. The fragipan acreage of 0.36 Mha is 9.5% of the land area of these parishes. Based upon current mapping, these values will more than double when mapping is completed. Mississippi has correlated 20 series in 65 counties representing 1.62 Mha or 16.5% of the acreages. Soil mapping in Oklahoma has been completed, and eight fragipan soil series have been mapped in 11 counties, which constitute 0.08 Mha. Tennessee has the most fragipan soil series (33 in 41 countries) of these six states. These represent an acreage of 0.57 Mha or 11.4% of the mapped acreage. Tennessee also contains the greatest number of MLRAs and both mesic and thermic soil temperature regimes occur in the state. Texas has the fewest series and lowest acreage of fragipan soils in the states studied (three series in three counties, 16 151 ha). These soils occur in southeastern Texas near the ustic-udic soil moisture regime boundary. Mapping is not complete, but additional acreage is not expected. Fragipan soils have been mapped in 14 MLRAs in the south central states. These soils occur on old, stable landscapes to young land-

[1]Contribution from the Agronomy Dep., Louisiana Agric. Exp. Stn., Louisiana State University Agric. Ctr., Baton Rouge, LA 70803, and the USDA-SCS, South Natl. Tech. Ctr., Fort Worth, TX 76115. Approved for publication by the director of the Louisiana Agric. Exp. Stn. as manuscript no. 88-09-2371.

 Fragipans: Their Occurrence, Classification, and Genesis, SSSA Special Publication no. 24.

5 Fragipan Formation in Loess of the Midwestern United States[1]

D. P. Franzmeier, L. D. Norton, and G. C. Steinhardt

Purdue University
West Lafayette, Indiana

ABSTRACT

In the Midwest, large areas of soils with fragipans are found in Kentucky, Ohio, Indiana, and Missouri, and smaller areas are found in Illinois, Michigan, Minnesota, Wisconsin, and Kansas. They formed in loess, glacial till, weathered clastic rocks, and weathered limestone. Most of these soils are classified as Fragiudalfs or Fragiaqualfs. The loess-derived soils are most extensive. They have fragipan horizons (Bx) below argillic horizons (Bt) and may have an eluvial horizon (E or E ') between the two B horizons. Fragipans form readily in acid silty and loamy deposits that overlie less permeable material (bedrock, paleosols, or dense till) at a depth of 0.75 to 2.5 m where the slope is < 12%. In the process of fragipan formation, silicate minerals weather in upper horizons and release their weathering products to the soil solution. In the winter and early spring, Si-rich solutions leach downward and become perched over the less permeable material. During the summer, trees remove water preferentially to the silicic acid in solution, and the remaining solution is concentrated in the small pores. As water is removed from these pores, silica precipitates and forms bonds with M–O groups, where O is oxygen and M may be Al, Fe, Mg or Si, on the surfaces of particles around these pores. This bond can bridge between mineral grains. The first bonding is molecular in scale, but with time it can grow large enough to be seen with a scanning electron microscope or even with a light microscope. This bridging is responsible for the hardness and brittleness of the fragipan. Compared with trees, grasses take up more silicic acid from the soil solution and cause little or no concentration of silica in the soil pores. This might explain why fragipans do not occur in soils developed mainly under prairie vegetation.

Fragipans are important soil features in the midwestern USA. According to *Soil Taxonomy* (Soil Survey Staff, 1975), a fragipan usually lies below an eluvial horizon. It consists of loamy materials (mainly silt loam, loam, or sandy loam) low in organic matter. These materials are arranged in polygonal structural units (prisms) that are > 10 cm across, are brittle, have very

[1] Contribution from Agronomy Dep., Purdue Univ., West Lafayette, IN 47907. Published as Journal Paper no. 11 452 of the Purdue Univ. Agric. Exp. Stn.

6 Weathering Discontinuities: A Key to Fragipan Formation[1]

Neil E. Smeck

The Ohio State University
Columbus, Ohio

M. L. Thompson

Iowa State University
Ames, Iowa

L.D. Norton

Purdue University
West Lafayette, Indiana

M. J. Shipitalo

North Appalachian Experimental Watershed
Coshocton, Ohio

ABSTRACT

Recently, numerous studies of soils with fragipans have been conducted in Ohio. This chapter is an attempt to collate the Ohio data with that available in the literature in order to formulate a general theory applicable to the formation of fragipans. Six pedons were selected to illustrate various pedogenetic scenarios in Ohio resulting in fragipan development and contributing to the development of our theory. Based on data for these pedons, it is concluded that fragipans form at weathering discontinuities originating either as a result of a weathering front or due to the occurrence of a lithologic or chronologic discontinuity. Furthermore, it is speculated that fragipans form in proximity to weathering discontinuities due to an interaction between acid-weathering products and components present in relatively unweathered material to form a bonding agent. This theory is presented for additional testing and evaluation.

Many investigators have offered explanations for the compact nature and brittle behavior of fragipans that restrict water and root penetration. Basically, all published explanations invoke one or more of the following mechan-

[1] Salaries and research support provided by State and Federal funds appropriated to the Ohio Agric. Res. and Development Ctr., The Ohio State Univ. Journal Article no. 169-88.

7 Solution Chemistry of Fragipans—Thermodynamic Approach to Understanding Fragipan Formation[1]

A. D. Karathanasis

University of Kentucky
Lexington, Kentucky

ABSTRACT

Most of the pedological interpretations and speculations about fragipan development have focused primarily on macro- and micromorphological descriptions and physical, chemical, and mineralogical characterizations of the solid phase. It is surprising that, although fragipans are some of the least-changing soil horizons over time (restricted influxes-outfluxes due to their dense and brittle character, limited biotic activity), no attempt has been made to describe them thermodynamically. Steady-state compositions of soil solutions in contact with fragipan constituents should be valid indicators of fragipan evolution. Furthermore, the development of thermodynamic relationships describing solution-mineral interactions in fragipan and overlying nonfragipan horizons should be useful in the identification of mineral weathering trends typifying a fragipan pedogenic environment. This chapter discusses such a thermodynamic approach used in a study of loess-derived Fragiudalfs underlain by various lithologies in Kentucky. Solution chemistry, reactive fraction, and mineralogical composition evaluations of fragipans in these soils supported the hypothesis of a Si-rich amorphous aluminosilicate binding agent with a Si molar fraction ranging from 0.58 to 1.00. This amorphous aluminosilicate coating appears to be the initial product of feldspar weathering. It is proposed that precipitation of amorphous SiO_2 on the amorphous aluminosilicate surface from Si-saturated solutions during desiccation periods and subsequent irreversible induration leads into the formation of fragipans. The intensity of these processes is controlled by site geomorphological characteristics that determine the degree of fragipan development.

Pedologists in their long struggle to understand the processes responsible for fragipan formation have concentrated their efforts on morphological, physicochemical, and mineralogical characterizations of the solid phase

[1] Contribution from the Dep. of Agronomy, Univ. of Kentucky, Agric. Exp. Stn., Lexington, KY 40546. Journal article no. 88-3-79.

8 Physical Processes of Fragipan Formation[1]

R. B. Bryant

Cornell University
Ithaca, New York

ABSTRACT

An understanding of the relationships between fragipans and their occurrence in landscapes appears to lie partially with an understanding of the physical processes of soil formation that result in high bulk density, close-packed arrangements of grains, and coarse prismatic structure. With respect to fragipans formed in glacial-till deposits, compaction by the weight of the glacial ice mass does not fully explain fragipan features nor was it the last physical process to act on extensive areas of till-derived sediments that presently have fragipan features. Micromorphological studies of fragipans provide little evidence in support of the hypothesis that physical characteristics of fragipans are the result of the process of alternating cycles of shrink/swell and infilling of pores. The initial desiccation of a wet soil mass that occurs during the physical ripening process seems capable of producing the bulk density, close-packed arrangements of grains, and coarse prismatic structure associated with fragipans. Subsequent wetting and drying cycles probably cause little alteration of soil structure and skeletal grain arrangement in subsurface horizons having low COLE values. The physical ripening process follows draining of a water-deposited sediment, deposition of a melt-out till deposit, congeliturbation, solifluction, wet-mass colluviation, and melting of a permafrost. Self-weight collapse of a wetted sediment and subsequent physical ripening is proposed as a physical process of fragipan formation in loess deposits in the lower Mississippi Valley.

Definitions of the fragipan (modified from L. "fragilis," brittle, and pan—Soil Survey Staff, 1975) are inextricably linked to soil physical properties. A combination of properties of fragipans results in a soil condition that is seemingly cemented when dry, slightly brittle or weakly cemented when moist, but slakes in water. However, the combination of soil-forming factors and processes that result in this condition and explain its occurrence and distribution in landscapes are as yet not fully understood.

In this chapter, distinctions are made among: (i) physical characteristics of parent materials that appear to be prerequisites to fragipan forma-

[1]Contribution from the Dep. of Agronomy, Cornell Univ., Ithaca, NY 14853.

 Fragipans: Their Occurrence, Classification, and Genesis, SSSA Special Publication no. 24.

9 Summary

Neil E. Smeck

The Ohio State University
Columbus, Ohio

Edward J. Ciolkosz

The Pennsylvania State University
University Park, Pennsylvania

Besides serving as a concise statement of major points in the prior eight papers in this publication, this summary should serve to steer the reader to the paper that best addresses a particular point of interest. All of the citations in this summary are to the papers comprising this publication, thus no dates or references are provided.

Witty and Knox indicate that fragipans occur primarily in mid-latitude, medium-textured, acid materials, with udic or aquic moisture regimes. Data provided by Witty and Knox show that >75% of the fragipans in the USA occur in Pennsylvania, Arkansas, Mississippi, New York, Ohio, Kentucky, Indiana, and Missouri. Smith and Daniels and Lindbo and Veneman indicate that many soils on the Coastal Plain and in the Northeast, respectively, were formerly considered to have fragipans, but based on current interpretations are classified without fragipans. Smith and Daniels indicate that 500 000 ha have been reclassified on the Coastal Plain. The authors of the papers for both of these regions indicate that most of the soils that have been reclassified possess many of the properties of fragipans that affect root growth and water movement. Thus, it is strongly recommended that fragi subgroups be established for such soils. Smith and Daniels propose that fragi subgroups be established for Hapludults, Kandiudults, and Kanhapludults; Lindbo and Veneman recommend that fragi subgroups be established for Inceptisols.

As suggested by their distribution, fragipans form primarily under forest vegetation and in various parent materials including glacial drift, loess, colluvium, lacustrine deposits, and alluvium. Whereas one characteristic noted in the definition of fragipans is that they generally contain <35% clay, Lindbo and Veneman conclude that fragipans only occur in materials with >35% clay plus silt. Furthermore, Hudnall and Williams suggest that in order for fragipans to form, there is a critical relationship between clay or silt plus clay and bulk density in the parent materials.

A recurring theme in the papers comprising this publication is that fragipans are very poorly defined. The lack of recognition of fragipans in many areas of the world may be due to the vague definition. Witty and Knox cite Guy Smith as indicating that the definition of the fragipan is "completely inadequate" for consistent identification. Witty and Knox emphatically state that the fragipan concept must be clarified and the definition revised. Two of the major problems with the fragipan concept is verification of pedogenic origin and quantification of brittleness. Although brittleness is one of the most diagnostic characteristics of fragipans, the determination of brittleness is currently too subjective for reliable and consistent identification purposes. Thus, accessory characteristics such as slaking and occurrence of a polygonal pattern are used. Witty and Knox have suggested a revised definition of fragipan that is an improvement but an unequivocal definition awaits a better understanding of fragipan genesis.

As indicated by many of the authors, the genesis of fragipans with their high bulk density and unique brittleness and slaking characteristics has been attributed in the literature to close packing, clay bridging, or bonding by an amorphous component. Bryant presents a strong case for the role of a physical process that results in high bulk density, close packing of grains, and coarse prismatic structure during fragipan formation. He refers to this process as physical ripening and suggests that it occurs during desiccation of initially slurred materials. Other than loess, most parent materials in which fragipans form are transported and/or deposited as a slurry and would be subject to the physical ripening process. Bryant suggests that loess upon wetting will collapse under its own weight. Following wetting and collapse, such self-weight collaspsing sediments are subject to desiccation and the physical ripening process. For fragipans in the Northeast, Lindbo and Veneman favor a clay bridging mechanism in the glacial tills, but for fragipans formed in nonglacial areas, they contend that both clay bridging and bonding by amorphous components play a role.

The work of Karathanasis has greatly strengthened the evidence favoring the role of amorphous bonding materials in fragipan development. Karathanasis has employed an innovative soil solution thermodynamic approach to reinforce prior work implicating amorphous Si or Si-rich aluminosilicates in the bonding of fragipans. Karathanasis concludes that fragipans are bonded by an Si-rich amorphous aluminosilicate with an Si molar fraction ranging from 0.58 to 1.00. Franzmeier et al. also favor fragipan bonding by an Si-rich amorphous precipitate and present a comprehensive theory for fragipan formation in loess mantled areas. They suggest that fragipan formation primarily occurs in loess deposits 0.75- to 2.5-m thick that occur over impermeable materials. Soluble weathering products (including Si) move down to the impermeable layer in percolating water. Further downward movement is restricted by the impermeable layer. Water is removed from the zone above the impermeable layer during periods of moisture deficit by transpiration. Transpiration by trees, however, results in preferential concentration of Si in the soil solution. Silica precipitates between grain contacts and in fine pores resulting in bonding and the characteristic brittleness of fragipans. Smeck et al. concur with the role of an amorphous Si-rich aluminosilicate but suggest that precipitation of the amorphous material is catalyzed by soluble components occurring in less weathered portions of the pedon. They conclude that fragipans form in proximity to weathering discontinuities, and suggest that the discontinuity promotes interaction between acid weathering products and components in relatively unweathered materials that results in the precipitation of the amorphous bonding agent.

In conclusion, it is evident that fragipans are not currently adequately defined for consistent identification throughout the world. Fragi subgroups should be established for many soils not considered to possess fragipans but exhibiting many of the characteristics of fragipans. It seems reasonable to conclude that all three mechanisms suggested (physical ripening, clay bridging, and bonding by an amorphous component) are involved in fragipan formation. The dominant mechanism may vary from pedon to pedon giving rise to the variety of fragipans that have been described and studied. Undoubtedly all three mechanisms play a role in the development of the best expressed fragipans. Furthermore the evidence for the existence of an amorphous Si-rich aluminosilicate bonding agent in fragipans is becoming conclusive.

It is apparent that the ideas, theories, and evidence presented in these papers are more complimentary than contradictory. Thus, a better understanding of fragipans is emerging, but additional work is necessary to complete the task.

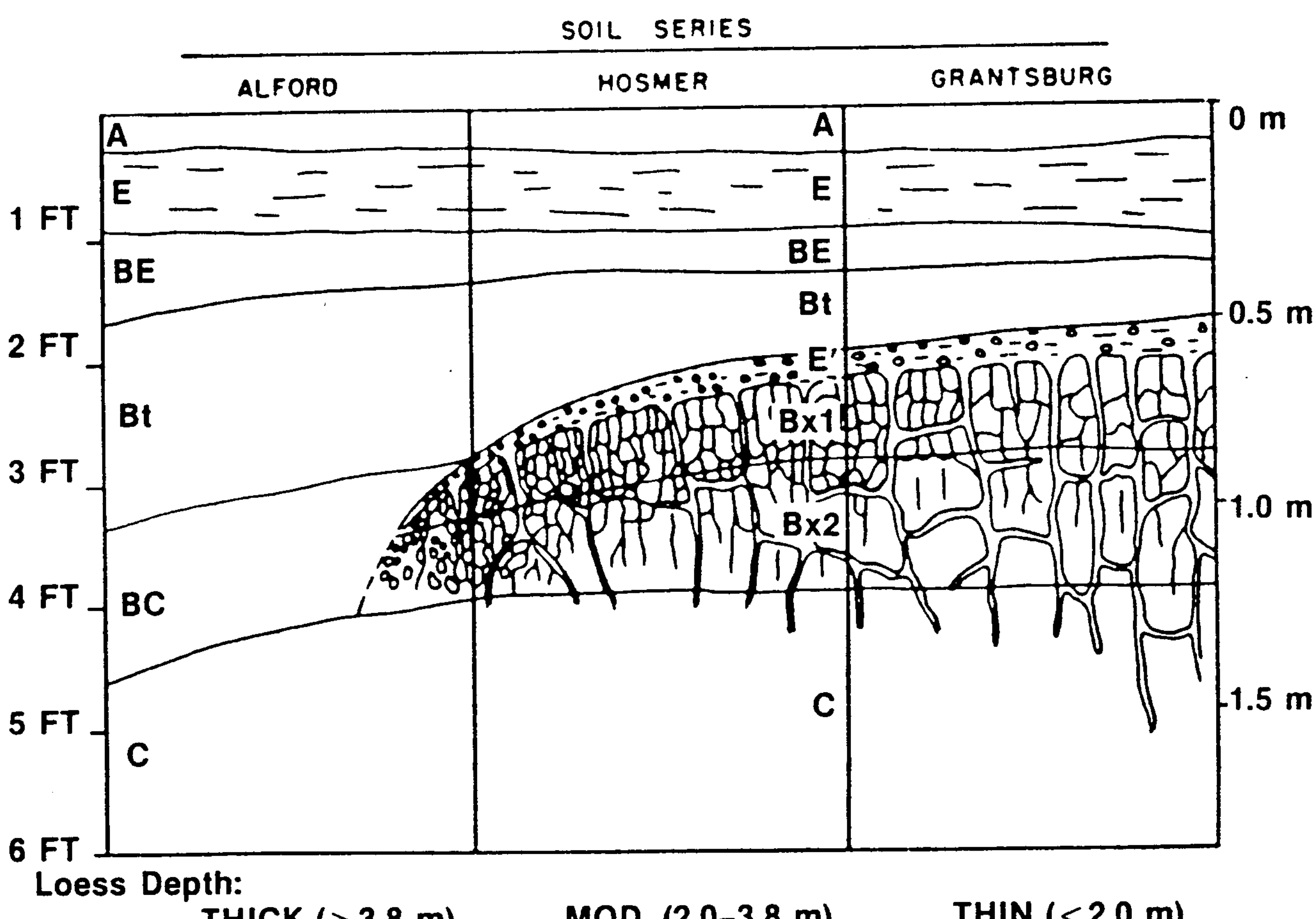


Fig. 5-2. Expression of fragipan development in relation to loess depth in southern Illinois (Gross-

02685691 CAB Accession Number: 931976784

Fragipan formation in argillic brown earths (Fragiudalfs) of the Milfield Plain, north-east England. I. Evidence for a periglacial stage of development.

Payton, R. W.
Department of Agricultural and Environmental Science, University of Newcastle upon Tyne NE1 7RU, UK.

Journal of Soil Science vol. 43 (4): p.621-644
Publication Year: 1992
ISSN: 0022-4588
Language: English
Document Type: Journal article

The parent materials, morphology and field relationships of soils with fragipans are described and analyses of their chemical and physical properties are presented. The soil materials have been affected by periglacial processes, including ice-wedge formation, the age of which has been established by reference to a buried palaeosol. The fine earth bulk density of the fragipans is between 1.75 and 1.91 g/cm3, whereas the density of overlying Eb horizons is <1.40 g/cm3. The formation of the compact lenticular structures and polygonal fissuring of fragipans is ascribed to the former presence of permafrost during the Loch Lomond Stadial 11 000 to 10 000 years B.P. The polygonal fissures, after subsequent infilling with illuvial materials, have determined the position of the greyish polygonal zones formed by the eluviation of Fe and Mn from fissure infill and fissure walls by redox processes. Clay migration from the Eb horizon into the fragipan is well marked. Clay and silt have also been locally removed from the upper parts of the greyish zones and redeposited towards their lower parts. Similar textural degradation has affected eluvial pockets in the upper fragipan. It is concluded that periglacial processes fully explain the genesis of macrostructural features but not the distinctive consistence of the fragipan. 59 ref.

DESCRIPTORS: Soil morphology; fragipans; formation; periglacial features; Soil types (genetic); Luvisols
IDENTIFIERS: argillic brown earths
GEOGRAPHIC NAMES: UK; England
BROADER TERMS: British Isles; Western Europe; Europe; Great Britain; UK
CABICODES: Soil Morphology, Formation & Classification (JJ400)

02863153 CAB Accession Number: 941904083

Fragipan formation in argillic brown earths (Fragiudalfs) of the Milfield Plain, north-east England. II. Post Devensian developmental processes and the origin of fragipan consistence.

Payton, R. W.
Department of Agricultural and Environmental Science, University of Newcastle upon Tyne, Newcastle upon Tyne, NE1 7RU, UK.

Journal of Soil Science vol. 44 (4): p.703-723
Publication Year: 1993
ISSN: 0022-4588
Language: English
Document Type: Journal article

Pedogenetic processes following a permafrost stage of development in four argillic brown earths with fragipans (Glossic and Ochreptic Fragiudalfs) are investigated by soil microscopy, including SEM observations of unimpregnated soil material, and by determination of clay mineralogy. Micromorphology of the apparently massive fragipan confirms both the presence of subhorizontal fissures infilled with illuvial deposits separating dense lenticular structures formed by ice-lens growth, and former vertical fissures formed by dessication on freezing with subsequent widening by ice-vein development. The firmness and brittle failure

of the fragipans are attributed to a closely-packed, well-graded matrix of skeleton grains bonded by clay bridges consisting of non-swelling illite and chlorite and to weak interconnection of macrovoids. Weak cementation is rejected as an explanation of fragipan consistence. Sequential stages of particle translocation have been critical to fragipan formation. High bulk density is attributed not only to irregular compression and contraction of the soil matrix under permafrost conditions but also to the infilling of voids by illuvial silt and clay. The full development of the fragipans has depended on Flandrian clay migration which has contributed to clay-bridge formation, void infilling and localized seasonal impedance of drainage resulting in eluviation of iron oxides, the development of grey polygonal patterning, and processes of degradation at the pan surface leading to glossic features. 49 ref.

DESCRIPTORS: soil morphology; fragipans; formation; soil types (genetic); Luvisols
GEOGRAPHIC NAMES: UK
BROADER TERMS: European Communities; British Isles; Western Europe; Europe; Commonwealth of Nations; Developed Countries; OECD Countries
CABICODES: Soil Morphology, Formation & Classification (JJ400)

02863154 CAB Accession Number: 941904084

Fragipan formation in argillic brown earths (Fragiudalfs) of the Milfield Plain, north-east England. III. Micromorphological, SEM and EDXRA studies of fragipan degradation and the development of glossic features.

Payton, R. W.
Department of Agricultural and Environmental Science, University of Newcastle upon Tyne, Newcastle upon Tyne NE1 7RU, UK.

Journal of Soil Science vol. 44 (4): p.725-739
Publication Year: 1993
ISSN: 0022-4588
Language: English
Document Type: Journal article

The micromorphology of eluvial and glossic areas with weak soil strength from the upper fragipan, and the upper parts of grey polygonal zones, in some argillic brown earths (Glossic Fragiudalfs) from north-east England shows unstable void walls stripped of clay with remnants of ferri-argillans, pale grey grainy clay clatings and darker grainy coatings. These occur alongside loose surface residues of skeleton grains and thin grey fine silt coatings of quartz and muscovite. SEM and EDAX studies of coating surfaces, and optical microscopy, SEM and EDXRA of very thin polished sections, show that some grain clay coatings form as alteration rims of ferri-argillans through localized waterlogging, iron oxide loss and micro-erosion leading to micropitting and disoriented fabrics. The inclusion of coarse clay to fine silt-sized quartz, felspar and muscovite in other grain coatings suggests either alteration of impure ferri-argillans or accumulation of degradational products derived from elsewhere on void walls. This is more certainly the case for dark grainy coatings in layered compound illuviation coatings adjacent to glossic areas. These fragipans are degrading from the top downwards by processes which are partly a consequence of the effects that the fragipan has on water percolation and root penetration. The destabilization of void walls, the degradation of ferri-argillans and the remobilization of clay to form glossic features did not begin until seasonal waterlogging in parts of the upper pan was sufficient to mobilize iron. 20 ref.

DESCRIPTORS: soil morphology; fragipans; soil micromorphology; soil types (genetic); Luvisols
GEOGRAPHIC NAMES: UK
BROADER TERMS: European Communities; British Isles; Western Europe; Europe; Commonwealth of Nations; Developed Countries; OECD Countries
CABICODES: Soil Morphology, Formation & Classification (JJ400)

Professor Wang Jingtai

Wang Jingtai was the founding Director of the Geological Hazards Institute of the Gansu Academy of Sciences in Lanzhou, and instrumental in setting up the research programme, involving collaboration with several Western European countries, which has shed so much light on the catastrophic landslides characteristic of the thick wind-blown deposits ("loess") of north China.

This ambitious and innovative field research began, with the aid of European Community and Gansu provincial government finance, in 1987 and is not scheduled for completion until summer 1995. It is less than a year since Wang led a Gansu government delegation to France, Belgium, the Netherlands and the United Kingdom, and presented a memorable keynote lecture on modern dust-storms in China during the International Union for Quaternary Research/Quaternary Resarch Association's conference at Royal Holloway, London University, on "Wind Blown Sediments in the Quaternary Record".

Wang was born of a farming family in Jing-Yuan County, Gansu Province, in 1935. His early promise was rewarded by a place in the renowned Department of Geology of Northwestern University in Xian, Shaanxi Province, from which he graduated with distinction in 1960. He moved immediately to a Lectureship in the joint Department of Geography and Geology at Hua-Dong Normal University in Shanghai, where he taught Quaternary geology, mineralogy and lithology and worked on research into the sediments of the shallow offshore parts of the East China Sea and the recent history of its coastal changes, a subject dealt with in several of his early papers. It was consistent with this initial work that, in 1969, he moved to the Department of Marine Geology at Tong-ji University in Shanghai. The succeeding nine years saw his growth into a mature earth science researcher as he became involved in, and then directed, programmes in the sedimentology and evolution of the great deltas of the Chang Jiang (Yangtze) River and the Hwang He (Yellow) River.

After 18 years in Shanghai, Wang was spotted by the remarkable scholar Professor Shi Yafeng who, as Director of the Institute of Glaciology and Geocryology of the Chinese Academy of Sciences, lured Wang back to Lanzhou, the capital city of Gansu. Wang turned to the challenge of glacial geology in remote regions of Tibet and Xinjiang with characteristic style and vigour. As a research associate he obtained wide experience of China's "wild west" and rose to the rank of Associate Professor and then to Directorship of the Glacial Division of the institute. His researches and publications on the evidence for climatic change over the past two to three million years drew him into studies of glacier variations, glacial sedimentology, frozen ground research, groundwater variations and, most important, the history of the great lakes of China's west. Several of the papers he published at this stage in his life have proved to be milestones both in content and approach.

Yet a further challenge lay ahead. In 1985, he was asked to take on the task of setting up the Geological Hazards Research Institute in Lanzhou city as the first (and still the only) natural hazard research institute in China. As an initiative by a Provincial rather than the Central Government this was from the first a remarkable venture. As the institute's Director, Wang was quick to see its potential, and became involved in a range of research and engineering and applied geology. Landslides, a regular source of fatalities in this part of China, occupied much of his attention.

It is a remarkable tribute to Wang's breadth of vision, however, that he never lost his almost child-like enthusiasm for the great puzzles posed by the Earth's changing climate as recorded in landforms and sediments. The enthusiasm lasted to the end. While in his hospital bed, he was involved (with one of his consultant surgeons) in drafting a new research programme in geomedical research.


Wang: landslide research

Wang was a man of great modesty and compassion. Many young scientists from the United Kingdom are indebted to him for the fundamental role he played in ensuring that their doctoral research programmes were completed both successfully and with great pleasure.

Edward Derbyshire

Wang Jingtai, earth scientist: born Jing-Yuan County, Gansu Province 30 December 1935; Lecturer, Department of Geography and Geology, Hua-Dong Normal University, Shanghai 1960-69; Researcher, Department of Marine Geology, Tong-ji University, Shanghai 1969-78; Research Associate, then Assistant Professor, then Director of the Glacial Division, Institute of Glaciology and Geocryology, Chinese Academy of Sciences 1978-85; Director, Geological Hazards Institute, Gansu Academy of Sciences, Lanzhou 1985-94; married Rong-Rong (one son, three daughters); died Lanzhou, Gansu Province 24 November 1994.

LöB
KOMMISSION
BERLIN 1995

PRESENT FUTURE PAST
INQUA BERLIN 1995