ARSOM - KAOW

BULLETIN DES SEANCES
MEDEDELINGEN DER ZITTINGEN

51 (3)

ACADEMIE ROYALE DES SCIENCES D'OUTRE-MER

Sous la Haute Protection du Roi

KONINKLIJKE ACADEMIE VOOR OVERZEESE WETENSCHAPPEN

Onder de Hoge Bescherming van de Koning

ISSN 0001-4176

2005

AVIS AUX AUTEURS

L'Académie publie les études dont la valeur scientifique a été reconnue par la Classe intéressée.

Les textes publiés par l'Académie n'engagent que la responsabilité de leurs auteurs.

BERICHT AAN DE AUTEURS

De Academie geeft de studies uit waarvan de wetenschappelijke waarde door de betrokken Klasse erkend werd.

De teksten door de Academie gepubliceerd verbinden slechts de verantwoordelijkheid van hun auteurs.

Abonnement 2005 (4 numéros — 4 nummers) : 70,00 €

rue Defacqz 1 boîte 3
B-1000 Bruxelles (Belgique)

Defacqzstraat 1 bus 3
B-1000 Brussel (België)

ARSOM-KAOW

BULLETIN DES SEANCES
MEDEDELINGEN DER ZITTINGEN

51 (3)

ACADEMIE ROYALE DES SCIENCES D'OUTRE-MER

Sous la Haute Protection du Roi

KONINKLIJKE ACADEMIE VOOR OVERZEESE WETENSCHAPPEN

Onder de Hoge Bescherming van de Koning

ISSN 0001-4176

2005

COMMUNICATIONS SCIENTIFIQUES

WETENSCHAPPELIJKE MEDEDELINGEN

Classe des Sciences morales et politiques

Klasse voor Morele en Politieke Wetenschappen

Bull. Séanc. Acad. R. Sci. Outre-Mer
Meded. Zitt. K. Acad. Overzeese Wet.
51 (2005-3): 217-229

L'origine romaine des fers à esclaves marocains*

par

Paul RAYMAEKERS**

MOTS-CLES. — Armée romaine; Esclavage arabe; Juifs marocains.

RESUME. — Au départ de razzias arabes à l'encontre des Noirs de l'Afrique occidentale, l'esclavage s'est perpétué au Maroc jusqu'au début du 20e siècle. Encore actuellement, il est fréquent d'observer chez les antiquaires du Sud-Maroc des menottes et fers à chevilles dont les modèles sont peu diversifiés. Des fouilles, réalisées dans les années 1960 par deux chercheurs allemands dans un camp militaire du Limes romain à proximité du Danube, ont permis la découverte d'entraves complètes destinées aux prisonniers de l'armée romaine. Le rapprochement des entraves de l'armée romaine et de celles observées au Maroc confirme une similitude technique étonnante, tant pour les serrures et les modes de fermeture manuelle que pour la typologie des chaînes utilisées. Cette survivance romaine au Maghreb résulte vraisemblablement de la très ancienne permanence d'artisans juifs marocains ayant repris à leur compte les modèles romains, et ce, jusqu'à leur départ massif vers 1960.

TREFWOORDEN. — Romeins leger; Arabische slavernij; Marokkaanse Joden.

SAMENVATTING. — *De Romeinse oorsprong van de Marokkaanse slavenijzers.* — Vertrekkend van de Arabische razzia's tegen de Zwarten van West-Afrika, is de slavernij in Marokko blijven voortduren tot het begin van de 20ste eeuw. Nu nog valt het vaak voor dat men bij de antiekhandelaars in Zuid-Marokko handboeien en enkelijzers vindt die, wat het model betreft, weinig verscheidenheid vertonen. Opgravingen door twee Duitse vorsers in de jaren 1960 uitgevoerd in een legerkamp van het Romeinse Limes bij de Donau leidden tot de ontdekking van kluisters bestemd voor de gevangenen van het Romeinse leger. De vergelijking van de boeien van het Romeinse leger met deze van Marokko bevestigt een verbazingwekkende technische gelijkenis, zowel op het vlak van de sloten als wat de manuele sluiting en de typologie van de gebruikte kettingen betreft. Deze Romeinse overleving in de Maghreb vloeit waarschijnlijk voort uit de oeroude bestendigheid van Marokkaans-Joodse ambachtslieden die zich het Romeinse model eigen maakten, en dit tot hun massale vertrek rond 1960.

KEYWORDS. — Roman Army; Arab Slavery; Moroccan Jews.

SUMMARY. — *The Moroccan Slave Fetters' Roman Origin.* — Starting from Arab razzias against black people from West Africa, slavery lasted in Morocco until the early 20th

---

* Communication présentée à la séance de la Classe des Sciences morales et politiques tenue le 15 mars 2005. Texte reçu le 21 décembre 2005.
** Membre de l'Académie.

century. Still today, handcuffs and ankle fetters of little model variety are frequently seen in South-Moroccan antique shops. Excavations carried out by two German investigators in the 1960s, in a military camp of the Roman Limes close to the Danube River, led to the discovery of complete iron fetters used for Roman army prisoners. The comparison between these cuffs and those from Morocco shows amazing technical similarities between the locks, the manual closing modes and the design of the chains used. Such a Roman survival results most probably from the lengthy period in which Jewish craftsmen settled in Morocco and made the Roman models' design their own, and this up to their mass exodus around 1960.

1. Entraves marocaines

1.1. Note introductive

Au départ d'observations effectuées auprès d'antiquaires et de brocanteurs du Sud-Maroc, l'examen de quarante entraves en fer comportant dix-huit menottes et vingt-deux fers de chevilles a pu être réalisé.

De telles entraves ont été abondamment utilisées jusqu'au début du 20e siècle dans le commerce marocain des esclaves africains en provenance d'Afrique occidentale; en 1910 s'observait toujours, à Marrakech, un marché d'esclaves.

Actuellement encore, ces fers sont parfois utilisés en milieu rural marocain pour maîtriser des personnes atteintes de démence violente ou pour immobiliser des délinquants; ils sont employés aussi pour entraver des animaux.

On les observe également, récupérés par les studios de Ouarzazate, comme équipement des captifs dans les superproductions cinématographiques tournées en ces lieux (songez aux films: «Lawrence d'Arabie», «La Momie»,...). Une visite effectuée par les soins de l'auteur dans les dépôts d'accessoires des studios cinématographiques de Ouarzazate n'a pas apporté d'éléments nouveaux.

L'on sait aussi que jusqu'à une époque récente (vers 1960), ces fers, dont la typologie connaît un nombre limité de variantes, étaient fabriqués par des artisans juifs marocains.

Leur vente était courante dans tout le Maghreb, et il n'est pas exclu qu'au 17e siècle — et ce, jusqu'au milieu du 19e — certains négriers européens se soient approvisionnés chez les fabricants du Maghreb.

Le Français Boudriot, architecte naval, signale dans l'excellent ouvrage qu'il a consacré à «L'Aurore», navire négrier du 18e siècle, l'existence de fers similaires au Musée de l'Armée à Paris (en provenance de la prise d'Alger en 1830). Trois exemplaires de ces fers — avec fermeture à boucles polygonales et serrure à poussoir — sont également conservés au Musée des Salorges à Nantes, ville qui fut la base de nombreux négriers, tel le Gantois Piet - I. - Liévin van Alstein (1733-1793). Ces trois entraves (nos inv. 944.4.7; 2002.3.1; 2004.7.1) — dont l'origine au Musée des Salorges est inconnue — ne semblent pas relever de la Traite atlantique. Elles pourraient avoir été remises au musée par des «Français d'Algérie».

1.2. La «Collection» des quarante pieces marocaines

La «Collection» observée compte dix-huit menottes de poignets et vingt-deux fers de chevilles.

La typologie des menottes de poignets et des fers de chevilles étant identique, hormis évidemment le diamètre des manilles plus grand pour les fers de chevilles que pour les menottes de poignets, l'analyse effectuée concernera à la fois ces deux espèces d'entraves.

Il a été éliminé une paire de menottes «modernes» d'inspiration européenne, utilisant des cadenas.

La «Collection» concernera dès lors:

a) Quinze paires d'entraves à serrure sur la première manille et à fermeture à boucles polygonales sur la deuxième manille (fig. 1).
   Ces quinze paires précitées incluent:
   — Trois paires à serrure «à poussoir» et boucles polygonales (fig. 2);
   — Sept paires à serrure «à clé» et boucles polygonales (fig. 3);
   — Cinq paires à serrure «à vis» et boucles polygonales (fig. 4).

b) Vingt-quatre entraves immobilisant un seul membre et reliées à une chaîne coulissante (fig. 5).
   Ces vingt-quatre entraves précitées incluent:
   — Quinze entraves à boucles polygonales (fig. 6);
   — Neuf entraves avec double barrette (fig. 7).

L'affirmation de l'origine et de l'ancienneté des modèles de la «Collection» ici analysée est rendue possible suite aux résultats d'une campagne de fouilles menées par deux archéologues allemands: le Professeur Dr H. Schönberger (Francfort-sur-le-Main) et le Dr F. Hermann (Nuremberg).

2. Entraves de l'armée romaine

Menées par les chercheurs précités entre 1958 et 1966, ces fouilles s'effectuèrent au camp romain de Künzing/Quintana, en Allemagne, à proximité de la ville de Passau et du Danube. Ils découvrirent dans ce camp militaire, élément des fortifications du «Limes» romain établi contre les invasions venant de l'Est, un important dépôt d'armes et d'outillages datant de la première moitié du 3e siècle après J.-C.

Une publication éditée en 1972 par le «Limes-Museum, Aalen» décrit les fouilles réalisées et leurs résultats. Présentation est faite notamment de vingt-trois menottes avec serrure «à poussoir» (fig. 8) et du détail de leur système de fermeture (fig. 9).

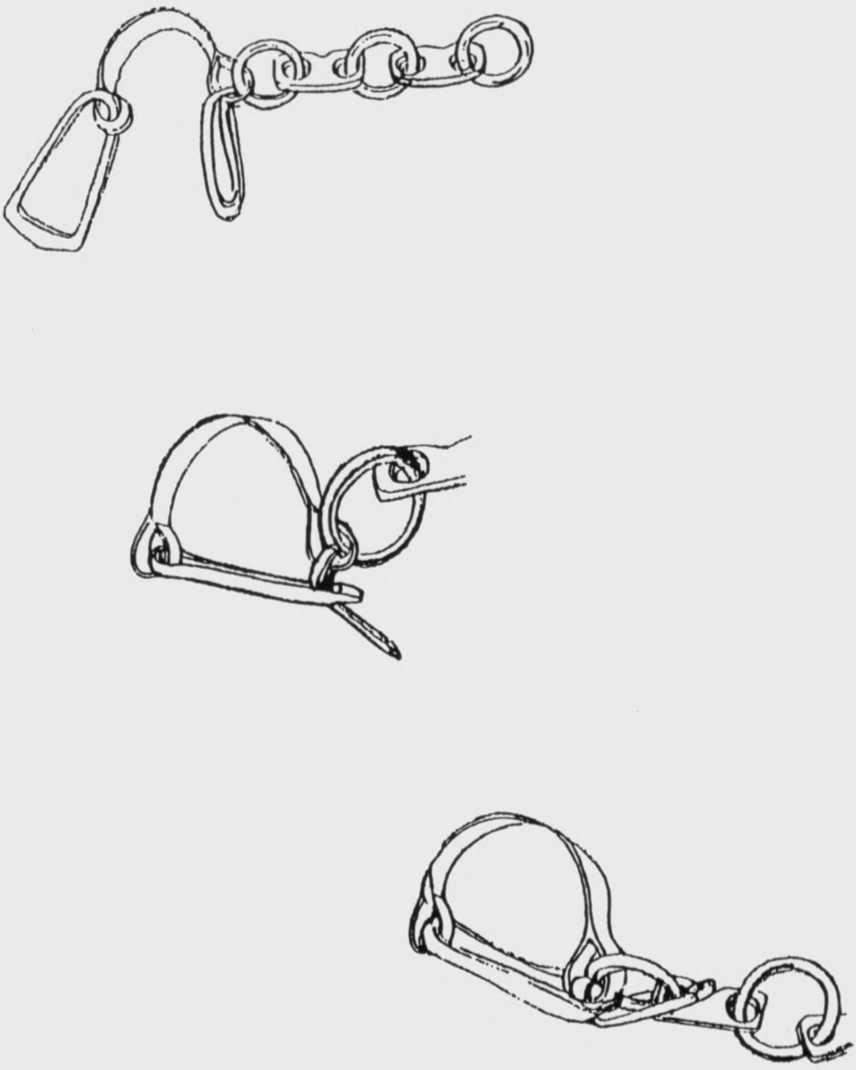


Fig. 1. — Système de fermeture «à boucles polygonales». Ce système très commun sur les entraves marocaines se retrouve déjà sur les entraves romaines du 3e siècle.

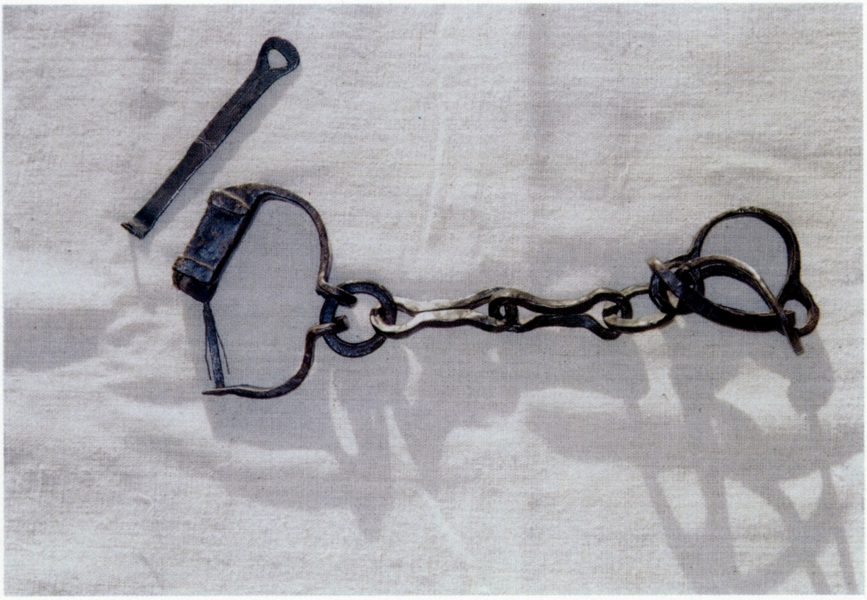


Fig. 2. — Menottes de poignets, à charnière, avec serrure «à poussoir» et fermeture à boucles polygonales (Maroc).

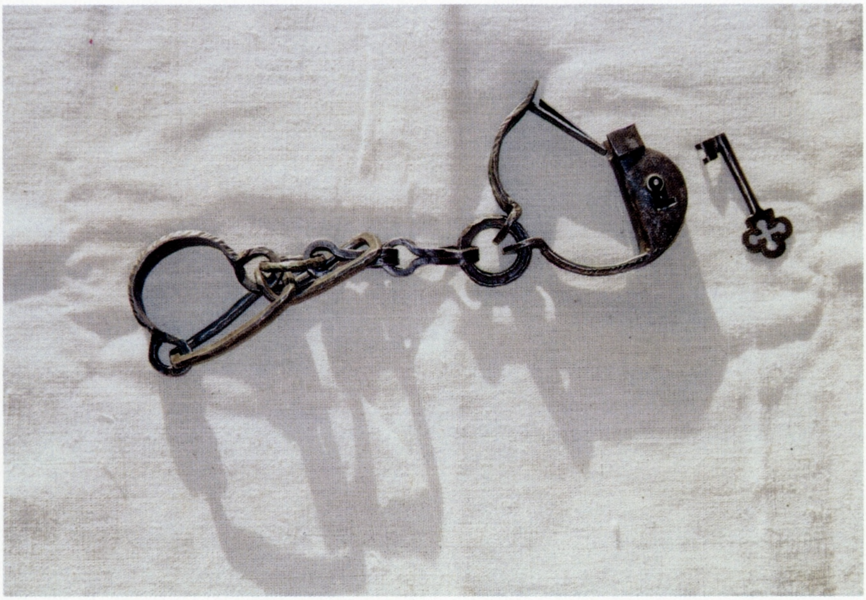


Fig. 3. — Menottes de poignets, à charnière, avec serrure «à clé» et fermeture à boucles polygonales (Maroc).

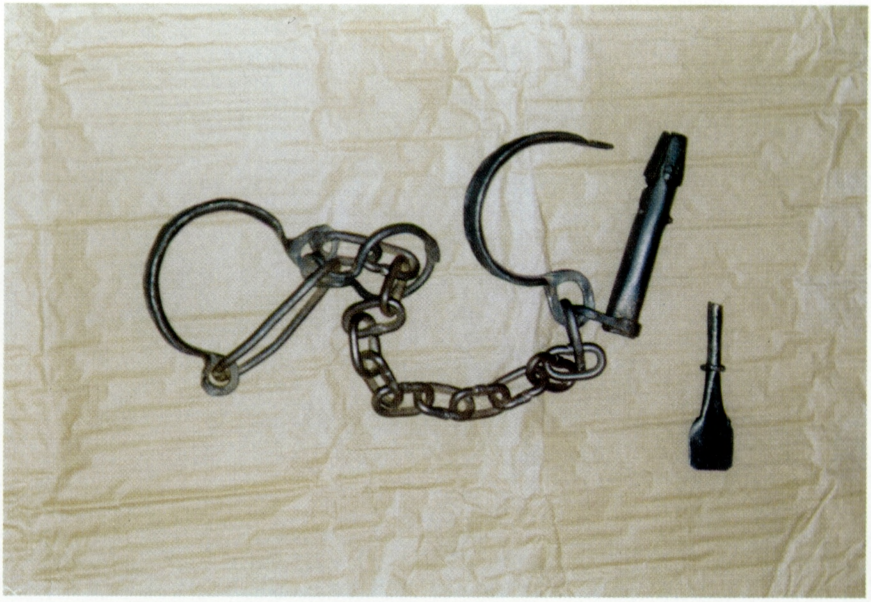


Fig. 4. — Menottes de poignets, avec serrure «à vis» et fermeture à boucles polygonales (Maroc).

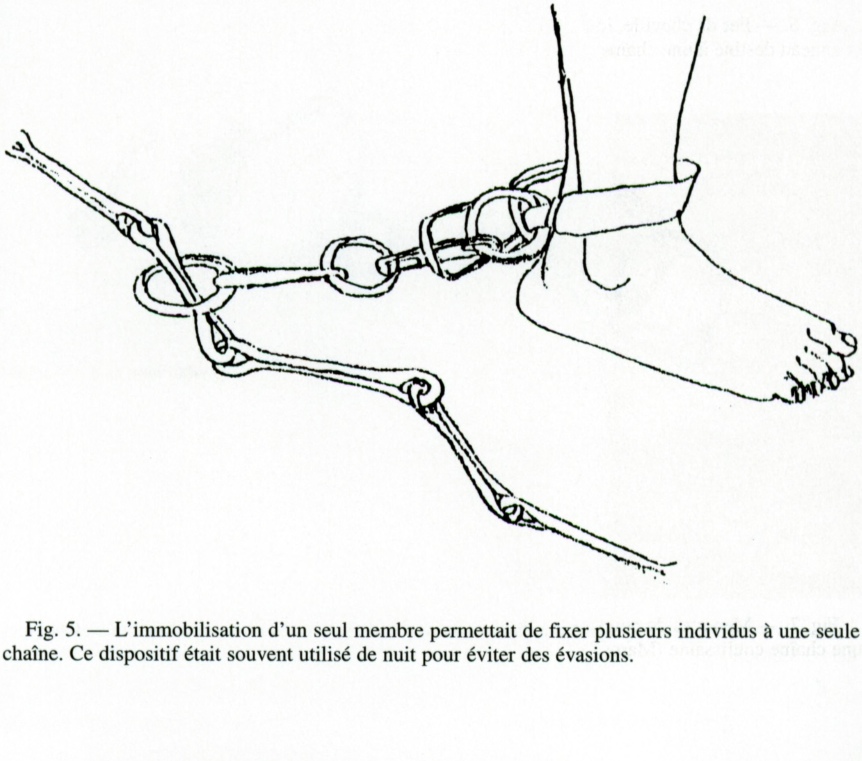


Fig. 5. — L'immobilisation d'un seul membre permettait de fixer plusieurs individus à une seule chaîne. Ce dispositif était souvent utilisé de nuit pour éviter des évasions.

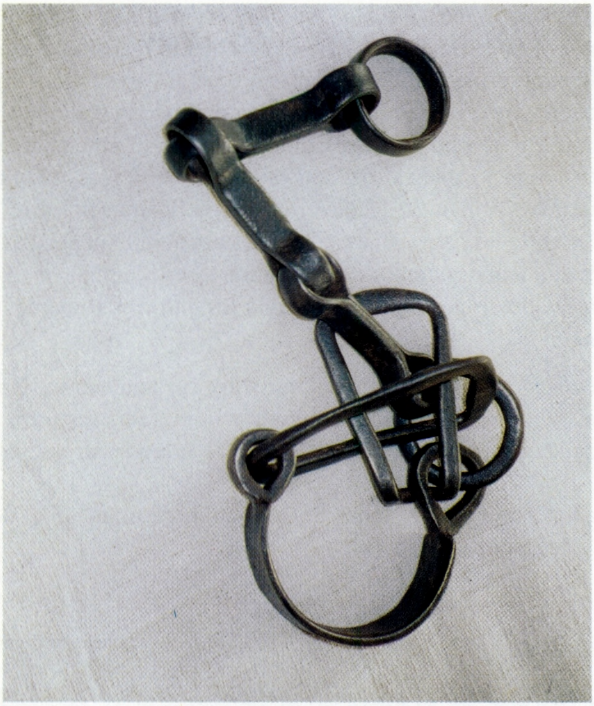


Fig. 6. — Fer de cheville, immobilisant un pied seulement, avec fermeture à boucles polygonales et anneau destiné à une chaîne coulissante (Maroc).

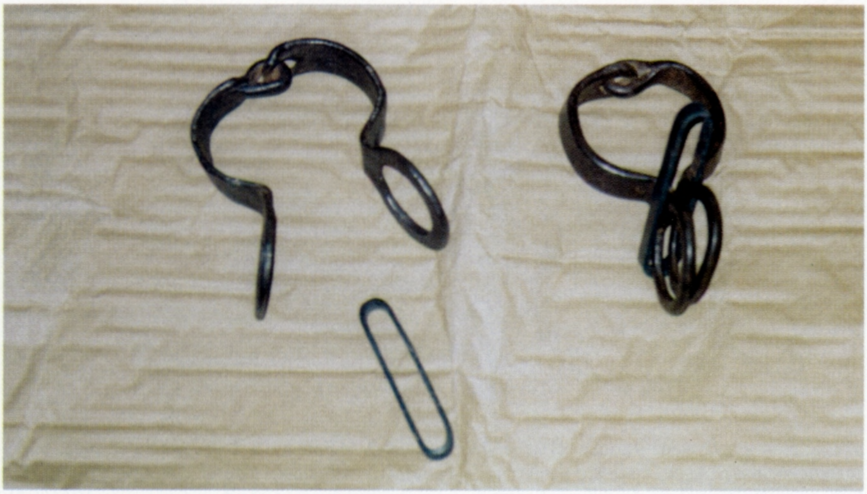


Fig. 7. — Menottes de poignets, à charnière, avec fermeture à double barrette, et anneau destiné à une chaîne coulissante (Maroc).

Les entraves de l'armée romaine se composent d'une menotte à charnière munie d'une serrure «à poussoir» reliée, par ailleurs, par une chaîne de 2 m de longueur, à une autre menotte à fermeture à double barrette, elle-même renforcée par une fermeture à boucle polygonale où coulisse la chaîne.

L'on notera qu'il ne sera pas tenu compte ici — sauf en ce qui concerne leur design — des longues chaînes (de 2 m de longueur) joignant les manilles des vingt-trois entraves romaines découvertes. La comparaison entre les entraves romaines et les entraves marocaines se limitera essentiellement aux manilles proprement dites et à leurs systèmes de fermeture.

Trois données précises caractérisent donc les entraves romaines découvertes en Allemagne:

1. L'existence d'une serrure «à poussoir» sur une entrave à charnière.
– Sur l'autre entrave à charnière non munie d'une serrure:

et/ou 2. L'existence d'un système de fermeture exercée par une double barrette.

et/ou 3. L'existence d'un système de fermeture résultant de l'utilisation de boucle(s) polygonale(s).

Fig. 8. — Entraves de l'armée romaine, découvertes en Allemagne à proximité du «Limes». Une manille, à charnière, se ferme par une serrure «à poussoir» totalement identique aux serrures de certains modèles marocains, tandis que l'autre manille, à charnière également, se ferme simultanément par une double barrette et une fermeture à boucles polygonales, systèmes retrouvés — indépendants — sur les entraves marocaines (photo: Bayer, München).

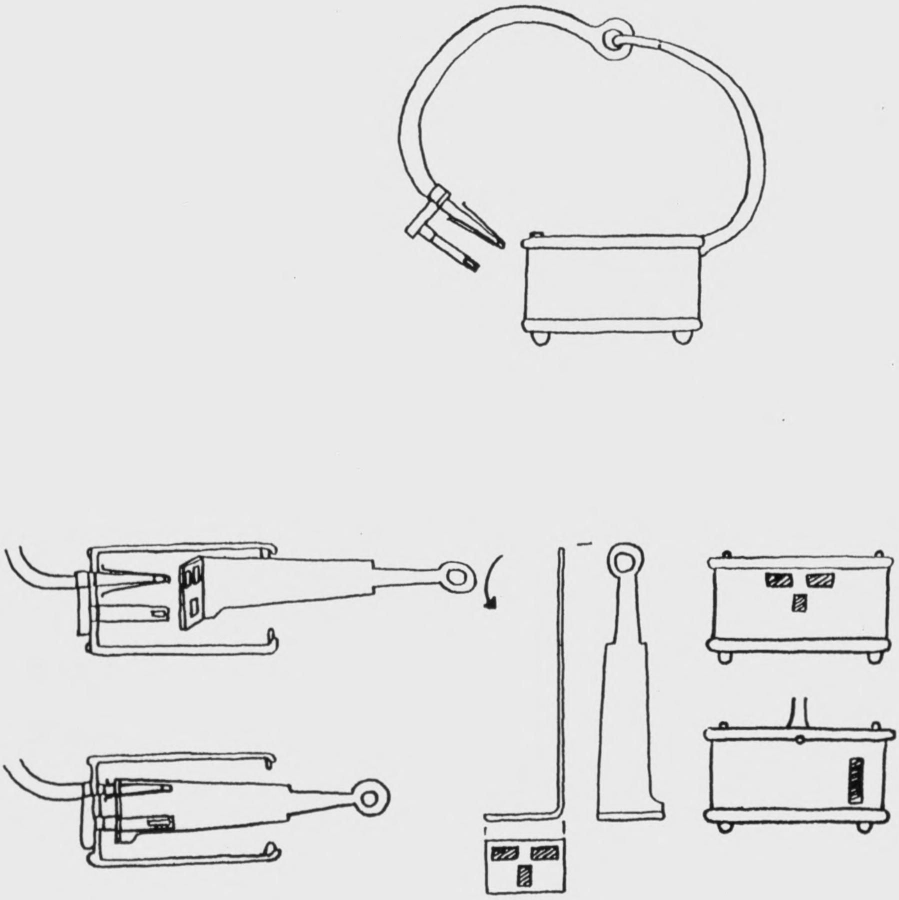


Fig. 9. — Le mécanisme du système de serrure «à poussoir» romain est en tous points identique au mécanisme marocain.

3. Comparaison des entraves marocaines et romaines

Les entraves marocaines analysées possèdent — en tout ou en partie — les données susdites caractérisant les entraves romaines du 3e siècle après J.-C. découvertes en Allemagne. Ce constat est confirmé par le tableau 1.

Tableau 1

Caractéristiques romaines retrouvées dans une «Collection» de quarante entraves marocaines

Description	Serrure "à poussoir" sur entrave à charnière	FERMETURE A : double barrette ET/OU boucles polygonales Sur entrave non munie de serrure	
		double barrette	boucles polygonales
a. 15 PAIRES D'ENTRAVES A SERRURE + BOUCLES POLYGONALES			
3 Serrures "à poussoir"	3 unités (a)	---	3 unités (b)
7 Serrures "à clé"	---	---	7 unités
5 Serrures "à vis"	---	---	5 unités
b. 24 ENTRAVES POUR UN SEUL MEMBRE : 15 à boucles polygonales	---	---	15 unités
9 à double barrette	---	9 unités	---
	3 unités	9 unités	30 unités

Commentaires:

1. Trois entraves marocaines sont identiques — double barrette en moins — aux entraves romaines du 3e siècle après J.-C.
2. Le solde des trente-six entraves marocaines observées présente — sans exception — une caractéristique similaire indiscutable à celle des entraves romaines, soit vingt-sept fermetures à boucles polygonales et neuf fermetures à double barrette sur les entraves non munies de serrure «à poussoir».
3. L'observation d'un nombre relativement restreint de serrures «romaines à poussoir» — trois unités — s'explique du fait de l'évolution technique des serrures entre le 3e et le 20e siècle. Des serrures «à clé» ont succédé peu à peu aux serrures «à poussoir». L'on notera que dans ces serrures «à clé» le ressort utilisé demeure identique à celui des serrures «romaines à poussoir», ce qui n'est pas toujours le cas sur les serrures «à clé» utilisées au Moyen-Age. Ces serrures «à clé» seront suivies par des serrures «à vis» toujours utilisées dans certaines menottes modernes, telles les menottes de la police et de l'armée anglaises (marque HIATT, par exemple).
   La collection examinée comprend sept serrures «à clé» (menottes uniquement) et cinq serrures «à vis» (dont une paire de menottes seulement).

Il est intéressant de noter que deux entraves avec serrure «à vis» et fermeture à boucles polygonales sur l'entrave non munie de serrure, en tous points comparables aux entraves marocaines de ce type, ont été observées en Cappadoce (Turquie). Elles pourraient dater de l'époque ottomane.

Intéressant également, dans le périodique *Dossiers de l'Archéologie*, le signalement par Michaël Mc Cormick d'une entrave de fer provenant d'un site bulgare du 10e siècle (site du bourg slave de «Staré Zamky»/Brno-Lisen). Ici aussi l'influence romaine est évidente en se confirmant par l'existence du système de fermeture à double barrette déjà utilisé sur les entraves découvertes en Allemagne.

Par ailleurs, la chaîne reproduite dans le signalement précité et illustrée par un cliché de Ilya Propokov (Musée National d'Histoire, Sophia) est en tous points semblable à diverses chaînes observées au Maroc (fig. 10).

La typologie des chaînes concernées — en Bulgarie comme au Maroc à l'origine — dérive de celle utilisée par l'armée romaine du Bas-Empire pour la

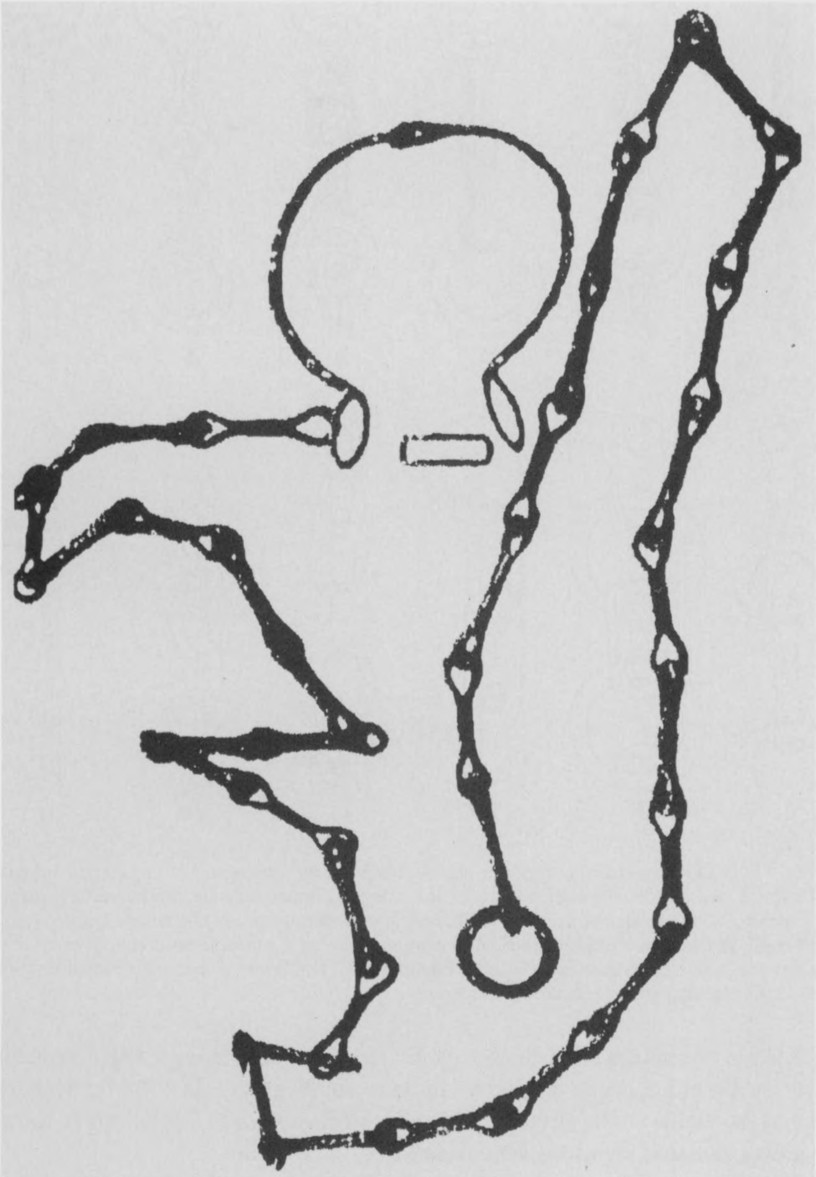


Fig. 10. — Collier en fer provenant d'un site bulgare du 10e siècle. On y retrouve le système romain de fermeture à double barrette, ainsi que le modèle de chaîne en usage dans l'armée romaine (photo: I. Prokopov, Musée national d'Histoire, Sofia).

Fig. 11. — Diverses chaînes observées sur les fers à esclaves marocains et une entrave romaine: 1. Chaîne à maillons doubles observée sur les menottes de l'armée romaine découvertes à proximité du Danube; 2-3. Chaînes marocaines à maillons doubles, identiques aux chaînes de l'armée romaine; 4-5-6-7-8. Diverses chaînes marocaines à maillons simples. Ce modèle est dérivé de ceux observés *sub* 1-2-3; 9. Chaîne marocaine à longs maillons; 10-11. Chaînes marocaines à maillons torsadés; 12. Chaîne marocaine à maillons «modernes».

confection de chaînes et de chaînettes. En témoigne encore récemment la découverte en Belgique d'une chaînette similaire sur le site de la Villa de Mageroy (Habay-la-Vieille), villa gérée à la fin du 3e siècle après J.-C. par l'armée romaine s'opposant aux invasions venues de l'Est.

A titre documentaire, les dessins présentés en figure 11 mettent en évidence l'évolution technique *in tempore* des chaînes utilisées sur les entraves marocaines.

Last but not least — avant de conclure — il sera précisé que, selon l'archéologue anglais Hugh Thompson dans sa communication magistrale «Iron Age and

Roman Slave Shackles», l'armée romaine avait en fait emprunté aux Celtes établis en Gaule le modèle d'entraves concerné. Thompson précise que les premiers spécimens d'entraves celtiques (à boucles polygonales) remontent à l'époque de Hallstatt (900-450 av. J.-C.), dite aussi Age de la Tène ou du second Age du Fer. Mais ceci est une autre histoire.

4. Conclusion

Il apparaît que la permanence de la fabrication des modèles romains d'entraves dans le Sud-Maroc, voire dans l'ensemble du Maghreb, s'explique par la présence constante, depuis une époque proche de la présence romaine, d'artisans juifs ayant repris à leur compte la technologie romaine.

Peut-être d'autres observateurs pourront-ils affiner ce constat.

Le sceau de Rome — et celui de la discipline de son armée — demeurent, plus de seize siècles après la fin de l'Empire, dans la périphérie de la *Mare Nostrum*, comme indélébiles.

BIBLIOGRAPHIE

Boudriot, J. 1984. Traite et navire négrier. L'Aurore. — Paris, éd. Ancre, 144 pp. + annexes.

Herrmann, F. R. 1972. Die Ausgrabungen in dem Kastell Künzing/Quintana. — Aalen, Limes-Museum, 8, 17 pp., 35 ph.

Mc Cormick, M. 2000. Les échanges au Moyen-Age (Voyageurs, monnaies et esclaves – Aux origines de l'économie européenne). — *Dossiers de l'Archéologie*, Dijon, **256** (sept. 2000): 44-47.

Thompson, H. 1993. Iron Age and Roman Slave Shackles. — *Archaeological Journal* (U.K.), **150**: 57-168.

Bull. Séanc. Acad. R. Sci. Outre-Mer
Meded. Zitt. K. Acad. Overzeese Wet.
51 (2005-3) : 231-249

The Fish Hunters of El-Hosh: Rock Art Research and Archaeological Investigations in Upper Egypt (1998-2004)*

by

Dirk HUYGE**

KEYWORDS. — Direct Dating; Fish Traps; Naqada II Period; Petroglyphs; Rock Art; Rock Varnish; Upper Egypt.

SUMMARY. — The occurrence of countless petroglyphs in the vicinity of the village of El-Hosh, about 30 km south of Edfu in Upper Egypt, has been known for over a century. In the 1930s, the German ethnographer Hans Winkler surveyed the area and published a number of rock drawings from El-Hosh. These include archaic-looking, curvilinear designs, often associated with a range of abstract and figurative motifs, including circles, ladder-shaped drawings, human figures, footprints, and crocodiles. In November 1998, an international team conducted a new rock art survey in the vicinity of El-Hosh. A multitude of sites with thousands of petroglyphs were located. Attention was paid mainly to the oldest manifestations of rock art in the area. Direct dating, using the Accelerator Mass Spectrometry ^{14}C method, indicates that some of these petroglyphs predate the early 7th millennium BP (mid-6th millennium cal BC), making it the oldest graphic activity ever recorded in the Nile Valley. Further archaeological research in March-April 2004 failed to produce evidence regarding the creators of this rock art, but led, among other things, to the discovery of an intact prehistoric tomb of the Naqada II period (*c.* 3500-3200 BC).

TREFWOORDEN. — Directe datering; Visvallen; Naqada II periode; Petrogliefen; Rotskunst; Rotsvernis; Boven-Egypte.

SAMENVATTING. — *De visjagers van El-Hosh: rotskunstonderzoek en archeologische navorsingen in Boven-Egypte (1998-2004).* — Het voorkomen van ontelbare petrogliefen bij het dorp El-Hosh, ongeveer 30 km ten zuiden van Edfoe in Boven-Egypte, is al meer dan een eeuw bekend. In de jaren 1930 verkende de Duitse etnograaf Hans Winkler het gebied en publiceerde een aantal rotstekeningen van El-Hosh. Hiertoe behoren archaïsch aandoende kromlijnige motieven, vaak geassocieerd met een waaier van abstracte en figuratieve motieven, zoals cirkels, laddervormige tekeningen, menselijke figuren, voetafdrukken en krokodillen. In november 1998 voerde een internationaal team een nieuwe rotskunstverkenning uit in de nabijheid van El-Hosh. Een veelheid van sites met

* Paper presented at the meeting of the Section of Moral and Political Sciences held on 18 January 2005. Publication decision taken on 17 May 2005. Final text received on 31 May 2005.
** Curator Egyptian Collection at the Royal Museums of Art and History (RMAH), Jubelpark 10, B-1000 Brussels (Belgium).

duizenden petrogliefen werd gelokaliseerd. De aandacht ging voornamelijk uit naar de oudste manifestaties van rotskunst in het gebied. Directe datering, gebruikmakend van de *Accelerator Mass Spectrometry* ^{14}C methode, geeft aan dat sommige van deze rotstekeningen ouder zijn dan het vroege 7de millennium BP (midden-6de millennium v. Chr.). Het zou dus om de oudste kunst gaan die ooit in de Nijlvallei is aangetroffen. Verder archeologisch onderzoek in maart-april 2004 bracht geen informatie aan het licht betreffende de makers van deze rotskunst, maar leidde onder meer tot de ontdekking van een intact prehistorisch graf uit de Naqada II periode (c. 3500-3200 v. Chr.).

MOTS-CLES. — Datation directe; Enclos à poissons; Période Naqada II; Pétroglyphes; Art rupestre; Patine; Haute-Egypte.

RESUME. — *Les chasseurs de poissons d'El-Hosh: recherches en art rupestre et études archéologiques en Haute-Egypte (1998-2004).* — La présence d'innombrables pétroglyphes à proximité du village d'El-Hosh, à environ 30 km au sud d'Edfou en Haute-Egypte, est connue depuis plus d'un siècle. Dans les années 1930, l'ethnographe allemand Hans Winkler étudia la région et publia plusieurs dessins rupestres d'El-Hosh, parmi lesquels des tracés curvilignes d'aspect archaïque, fréquemment associés à toute une gamme d'éléments abstraits et figuratifs, dont des cercles, des «échelles», des figures humaines, des empreintes de pieds ou des crocodiles. En novembre 1998, une équipe internationale procéda à une nouvelle reconnaissance de l'art rupestre aux environs d'El-Hosh. A cette occasion, une multitude de sites comptant des milliers de pétroglyphes furent découverts. L'attention a principalement porté sur les manifestations graphiques les plus anciennes de la région. Depuis lors, des datations directes par *Accelerator Mass Spectrometry* ^{14}C indiquent que ces dessins sont antérieurs au début du 7^{e} millénaire BP (mi-6^{e} millénaire av. J.-C.). Il s'agirait donc de l'art le plus ancien jamais retrouvé dans la Vallée du Nil. Malgré des études archéologiques menées en mars-avril 2004, aucune information concernant les créateurs de cet art rupestre n'a été découverte jusqu'ici, mais ces travaux ont entraîné la mise au jour d'une tombe préhistorique intacte de la période Naqada II (vers 3500-3200 av. J.-C.).

1. Introduction

The occurrence of countless rock drawings in the vicinity of the village of El-Hosh, situated on the west bank of the Nile, about 30 km south of the Upper Egyptian town of Edfu (fig. 1), has been noted for over a century (CHESTER 1892). Up to now, however, this rock art had not been properly documented. The principal objective of the 1998 mission (HUYGE *et al.* 1998) was a detailed reconnaissance of the environs of El-Hosh and a systematic recording of a series of significant petroglyphs using standardized recording techniques (manual tracing on transparent plastic foil and photography). In addition, we intended to study the spatial distribution of the rock art sites with specific reference to the natural environment (the geomorphology of the area in particular). Another important aim was to establish a chronological and cultural-historical framework for this local rock art. This involved sampling of carbon-bearing substances associated

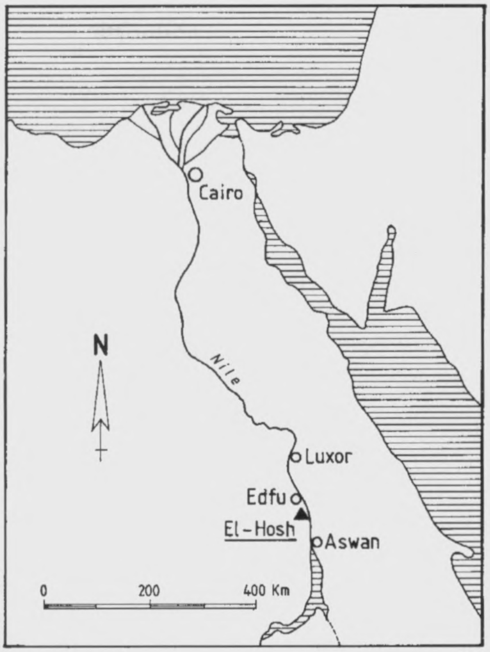


Fig. 1. — Map of the Egyptian Nile Valley, showing the location of El-Hosh.

with patina and rock varnish formed within petroglyphs. That carbon could then be applied for direct dating using the Accelerator Mass Spectrometry (AMS) ^{14}C method (TUNIZ & WATCHMAN 1994, WATCHMAN 2000). To date, this procedure has never been tested on African rock art. Further investigations in the area in 2004 aimed at producing archaeological evidence regarding the creators of rock art.

2. The 1998 Rock Art Survey

The November 1998 rock art survey was conducted in a 6 × 2-km stretch along the Nile between the village of El-Hosh in the north and the mouth of the Wadi el-Shatt el-Rigal in the south. A multitude of rock art sites were located containing several thousands of petroglyphs. Some of these had already been briefly explored in 1926 and 1937 by the *VIII. Deutsche Inner-Afrikanische Forschungsexpedition* (CERVICEK 1974) and the Sir Robert Mond Desert Expedition respectively (WINKLER 1938, 1939). Only very few drawings and photographs have been published to highlight the rock art of this area.

Fig. 2. — Geomorphologist Morgan De Dapper (left) and the author examining rock drawings at Abu Tanqurah Bahari (photo: R. Mommaerts).

As it was impossible to record the sites in their entirety, we decided to focus on the oldest manifestations of rock art present. Three different sites with archaic-looking designs were identified. These sites, large isolated hills of Early Cretaceous Nubian sandstone, are further subdivided into petroglyph localities and rock art panels. They are (from north to south): 1) Gebelet Yussef ("Yussef's Hillock"): nine petroglyph localities, twelve rock art panels; 2) Abu Tanqurah Bahari ("Abu Tanqurah North"): ten petroglyph localities, seventeen rock art panels (fig. 2); 3) Abu Tanqurah Qibli ("Abu Tanqurah South"): three petroglyph localities, seven rock art panels.

3. Nature of Rock Art

On the basis of the majority of subjects depicted (boats, anthropomorphic figures, and various species of animals), the bulk of rock art at El-Hosh belongs to the late prehistoric (Predynastic) and Early Dynastic periods (*c.* 4000-2650 BC [1]*). Many of the themes represented can closely be related to the

* The number in brackets [ ] refers to the note, p. 248.

Fig. 3. — Gebelet Yussef, Locality 1, Panel 1. The animal figures located in the upper right corner are more recent in age than the rest of the panel (tracing: E. Marchi and I. Regulski).

iconographical repertoire of the early Nilotic pastoral-agricultural civilizations. There is, however, a substantial number of intensively patinated, curvilinear designs, capped with mushroom-shaped or cordiform protuberances, which appear to date from another epoch. In some cases these drawings occur in large, complex panels (fig. 3), while in others in small clusters (fig. 4), and even, on occasion, as isolated figures. In several cases these motifs are seemingly associated with a wide range of more or less contemporaneous abstract and figurative motifs, including circles, ladder-shaped drawings, human figures, footprints, and crocodiles. In this contribution I will concentrate on the curious curvilinear designs.

Winkler, who published some retouched photos of the latter petroglyphs (1938: plate XXXII), considered the El-Hosh curvilinear drawings to be the representations of fish traps. According to him (1938: 31), each one of these designs shows a "gate" which opens on to a "corridor", leading in turn to the opening of the "heart". He concludes: "possibly these are designs of traps put in the current of the river as a primitive labyrinth in which to catch fish or other creatures". There is much to say in favour of Winkler's ingenious interpretation. Indeed, these sophisticated devices bear a remarkable likeness to the ground plan of a universally known fish trapping arrangement, namely the labyrinth fish fence (Herman 1901, von Brandt 1984). The examples shown in figure 5 represent ground plans of actual fish traps from Europe and Japan. They are illustrative and representative, however, for a type of device that is universally known. There

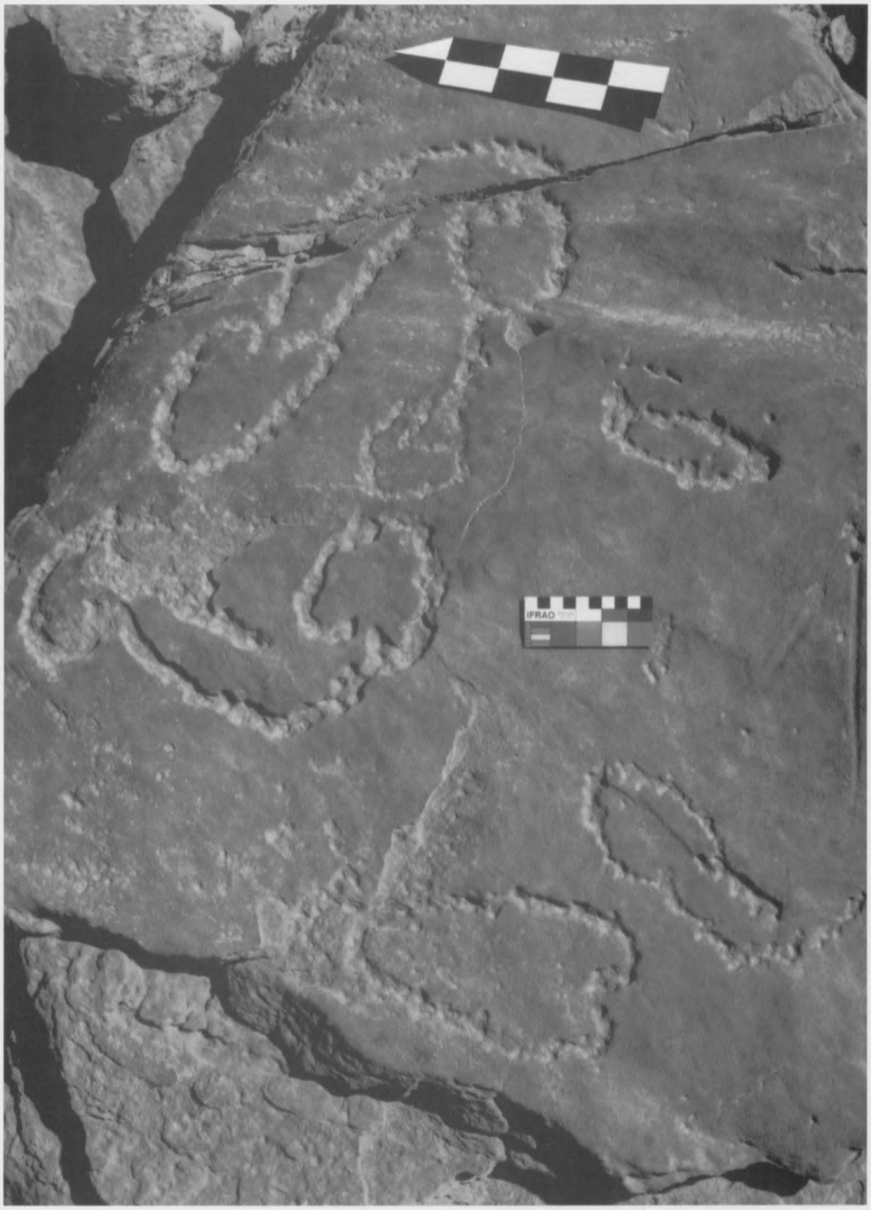


Fig. 4. — Abu Tanqurah Bahari, Locality 3, Panel 1. Small cluster of curvilinear motifs (photo: R. Mommaerts).

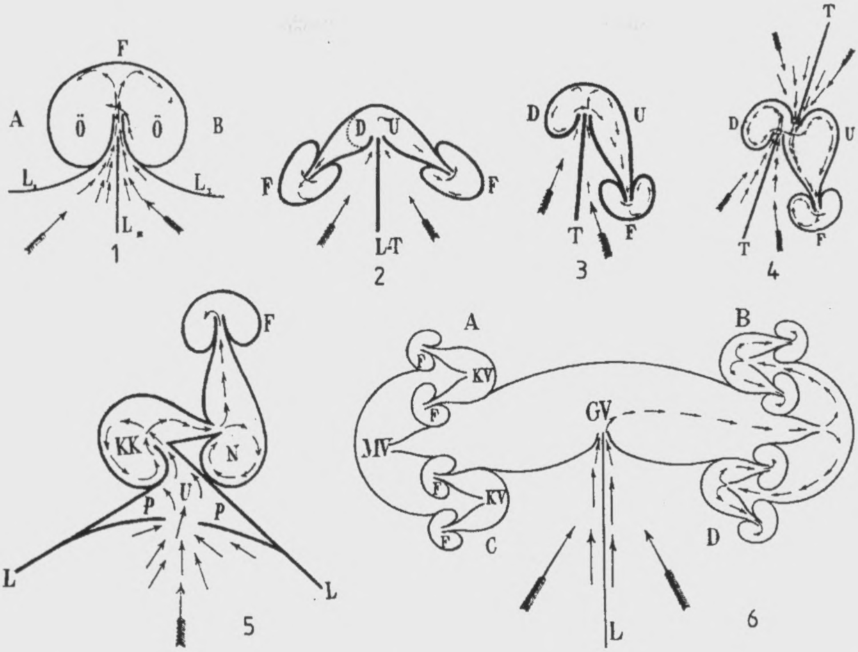


Fig. 5. — Ground plans of labyrinth fish fences from northern and eastern Europe (1-5) and Japan (6). Arrows indicate movement of fish (after HERMAN 1901).

are many different ways of constructing a labyrinth fish fence, but, ultimately, all are variations on a very similar basic design, namely that of figure 6. The general purpose of such a trap is to channel and barricade fish into a particular area or confined space (a catching chamber) where they can easily be speared, netted or simply collected by hand. Fish are driven into the trap by the current, receding waters or man-made noise, and are prevented from escaping by the narrow entrances and the sophisticated design of the walls which leads them to a never-ending, winding path. Examples from the ethnographic record indicate that the use of these fences is generally restricted to aquatic environments with a gradually sloping bed and a healthy supply of reeds or sticks required for their construction (BREWER & FRIEDMAN 1989). Alternatively, this type of trap (or certain parts of it) can be built of piled-up stones (SERJEANT 1968, DEACON 1984). In order for these devices to be effective, it is necessary to have openings ("gates") through which fish can enter. As exemplified by figures 3 and 4, such openings are always represented in the El-Hosh petroglyphs. Some examples are moreover provided with funnel-shaped, linear additions. These are probably "guiding walls" added to the device to direct fish into the trap.

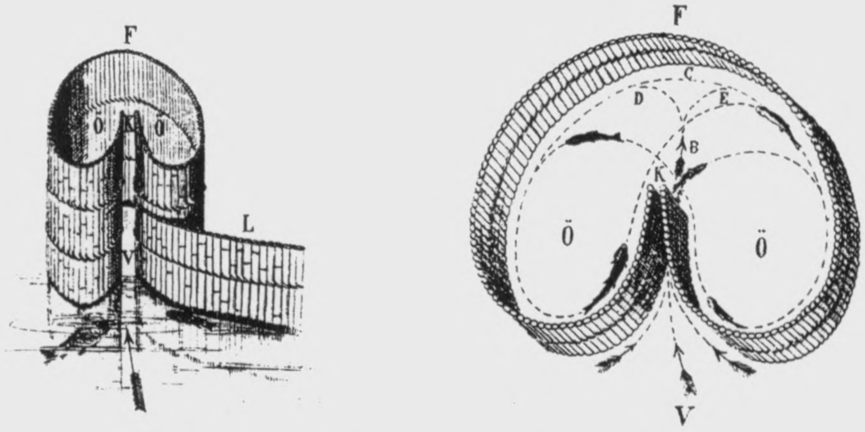


Fig. 6. — Basic forms of labyrinth fish fences (after HERMAN 1901).

Representations of labyrinth fish traps are unknown in classical Egyptian iconography. At first sight, this may seem strange in view of the abundance of fishing scenes in Pharaonic tomb paintings and reliefs (BREWER & FRIEDMAN 1989, VAN ELSBERGEN 1997, SAHRHAGE 1998). An obvious reason, however, for why they were not represented, could be that they are "passive" fishing gear, not requiring the constant attention and active intervention of humans, which evidently makes them less suitable subjects for the popular "animated" scenes of daily life commonly represented in tombs. Fortunately, we have some textual and iconographical evidence (from both classical authors and modern ethnographers) which attests to the use of this kind of fishing gear in the Nile Valley and the Delta during the Graeco-Roman Period and in modern times (BREWER & FRIEDMAN 1989). Figure 7, reproduced from an illustrious zoological atlas of Nile fishes (BOULENGER 1907), shows a modern example of such a trap in the vicinity of Aswan. The design of this trap is not completely identical to that of the El-Hosh specimens, but the principle is similar. At least this effectively demonstrates that the labyrinth fish fence was known in the Nile Valley and probably since early times. Remains of possible early examples of such traps, built of piled-up stone blocks, have been recovered near Abka in Lower Nubia (MYERS 1958).

4. Age of Rock Art

Let us, for the moment, accept that the reading of these petroglyphs as fish traps conforms to reality. How old can these rock drawings be? Remarkably, the El-Hosh rock art contains several examples of superimposition in which these

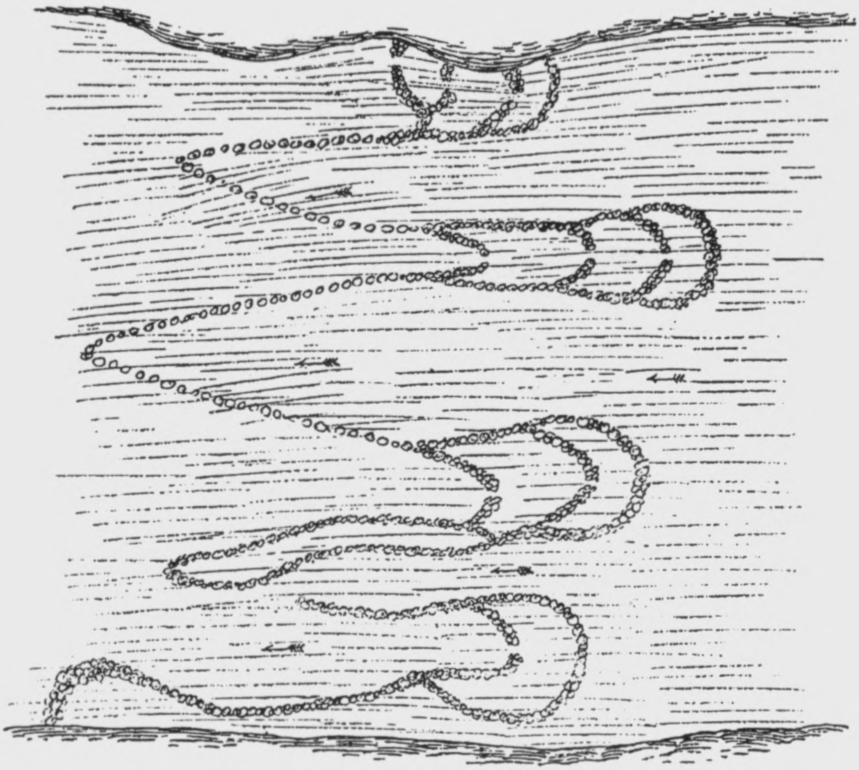


Fig. 7. — Early 20th-century fish trap in the vicinity of Aswan in Upper Egypt (after Boulenger 1907, fig. 24).

"fish trap" designs are superimposed by "stylized", bushy-tailed giraffe drawings (fig. 8). In early Egyptian iconography, "stylized" representations of giraffe are a prevalent subject on middle Predynastic (Naqada I) ceramics primarily (between *c.* 4000-3600 BC). On this basis, a middle Predynastic date can tentatively be accepted for the El-Hosh giraffe drawings (Huyge 1998a, 1998b, 1999). Moreover, as could be observed on various occasions, there is a substantial difference in degree of patination between the curvilinear designs and the giraffe drawings: complete *versus* advanced patination respectively. If this considerable difference in degree of patination has chronological relevance, it is likely that the curvilinear designs are early Predynastic (6th or 5th millennium BC) or possibly even late Palaeolithic in age (8th or 7th millennium BC, or earlier).

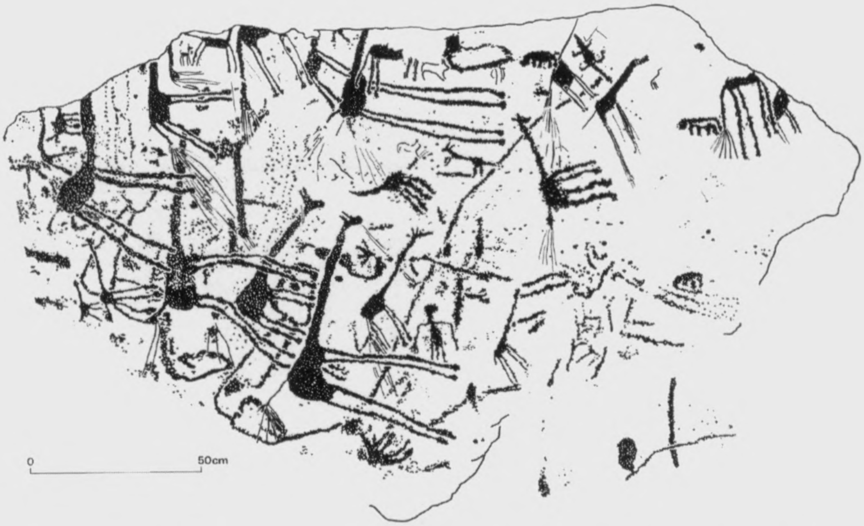


Fig. 8. — Gebelet Yussef, Locality 2, Panel 1. Note the superimposition of curvilinear fish trap motifs by bushy-tailed giraffe drawings (tracing: E. Marchi and I. Regulski).

This date, of course, needed to be confirmed by independent means. During the course of the survey, several rock art-bearing exposures of Nubian sandstone were inspected to determine the nature and extent of the formation of patina and rock varnish on petroglyphs, and to select potential motifs for sampling and possible AMS ^{14}C dating. Mineralogical and geochemical analyses (using petrography, X-Ray Diffractometry, combined Scanning Electron Microscopy and Energy Dispersive X-Ray Analysis, and Inductively Coupled Plasma Spectrometry) were used to determine whether the rock surface coatings are rock varnishes, formed by the accretion of aeolian components (clay minerals and other airborne particles), or effusive deposits resulting from leaching of iron (Fe) and manganese (Mn) minerals from the core to the surface of the rock (THOMAS 1997). The results indicate that the coatings are of composite nature and generally consist of a porous, silty, iron-rich basal layer resting on quartz grains of the rock and a finely laminated, manganese-rich surface layer. As iron, but little or no manganese, was substantially present within the underlying rock matrix, the basal layer of the patina was probably produced by *in situ* migration (leaching), whereas the upper layer was the result of the cementation of particles from atmospheric fall-out. In the course of the latter, external process, typical of true rock varnish formation, airborne organic matter could easily have been trapped within the developing coating.

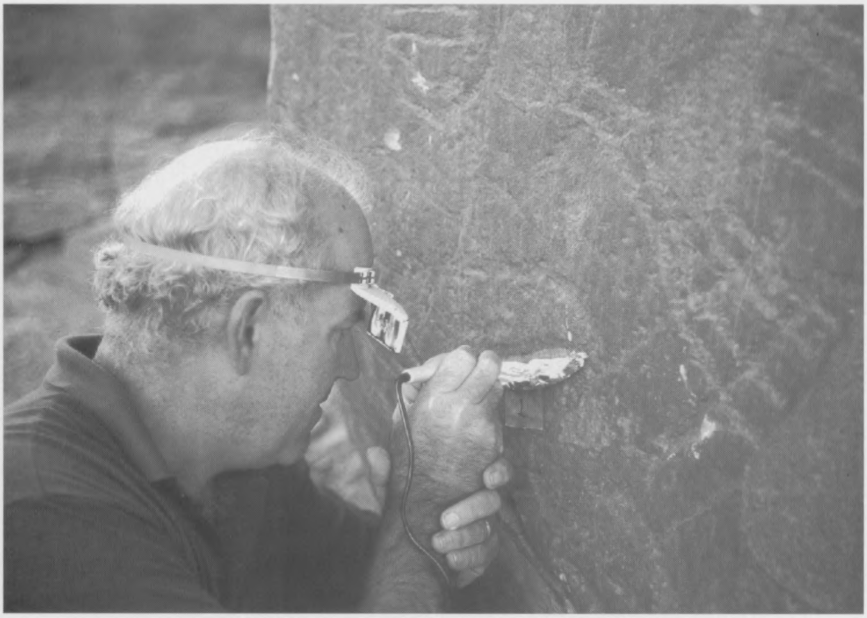


Fig. 9. — Alan Watchman sampling patinated deposits from within petroglyphs at Gebelet Yussef.

About forty samples of the dark patinated deposits from within petroglyphs and on the surrounding rocks were collected using a battery-powered engraving drill and dental burrs (fig. 9). For radiocarbon dating a selection of fifteen iron- and manganese-rich varnish coated quartz grain samples taken from within the petroglyphs themselves were submitted to the Center for AMS of Lawrence Livermore National Laboratory in Livermore (USA). Ultimately, only four of the fifteen processed samples, all of which were taken from typical "fish trap" motifs, contained sufficient carbon for measurement (Huyge *et al.* 2001). These four ^{14}C dates (tab. 1) provide minimum age estimates for both petroglyph production and rock varnish formation. The dated residual organic matter (plant cellulose fibres) is not fossilized and therefore stems from organisms living at the time of varnish formation. All four dates are therefore valid as *termini ante quem* for the petroglyphs. They document different stages of varnish formation. Whereas it is evident that the rock art must be older than 2450 ± 320/2280 ± 320 ^{14}C years BP (Third Intermediate Period to Ptolemaic Period at 68 % probability) and even 3740 ± 300 ^{14}C years BP (Old Kingdom to Middle Kingdom at 68 % probability), the date of 6690 ± 270 ^{14}C years BP (5900-5300 cal BC at 68 % probability) is outstanding. This age estimate indicates that the El-Hosh "fish trap" motifs are well beyond the age of any other graphic activity known in the Nile Valley. The oldest known dates for "art" in the Nile Valley (geometric

Table 1

AMS ^{14}C age determinations for rock varnishes covering "fish trap" petroglyphs at El-Hosh

Provenance of sample	CAMS no.*	BP**	σ***	cal BC****
Abu Tanqurah Bahari, Locality 2, Panel 1	57553	6690	270	5900 (68 %) 5300
Abu Tanqurah Bahari, Locality 7, Panel 1	60893	3740	300	2600 (68 %) 1700
Gebelet Yussef, Locality 2, Panel 1	60892	2450	320	1000 (68 %) 100
Abu Tanqurah Bahari, Locality 3, Panel 3	60891	2280	320	800 (68 %) AD 50

* CAMS: Center for AMS of Lawrence Livermore National Laboratory.
** BP: radiocarbon years before present.
*** σ: standard deviation.
**** cal BC, calibrated calendar years before Christ (calibration using OxCal Version 3.4).

and herringbone motifs on pottery and figurines made of bone and ivory) are related to the Upper-Egyptian Neolithic/Predynastic Badarian (~5600-5100 ^{14}C years BP or ~4500-4000 cal BC) and Lower-Egyptian Merimde cultures (*Urschicht* of this culture, dated ~5900-5800 ^{14}C years BP or ~4750-4650 cal BC) (HENDRICKX 1999).

An upper time limit for the El-Hosh "fish trap" petroglyphs is difficult to determine. Geomorphological evidence, in particular the inland occurrence of preserved bungs of black-coloured, compact, fossil flood silts at about +7 m above the modern floodplain (at about +102 m a.s.l.), indicates that the landscape surrounding the rock art sites, characterized by narrow and flat-bottomed wadi outlets, must have been eminently suitable for installing stationary fishing devices. Remnants of these same black silts have been observed elsewhere in the Upper-Egyptian Nile Valley (PAULISSEN *et al.* 1985). They seem to have been deposited during catastrophic floods by the so-called "Wild Nile" at around 13,000-12,000 ^{14}C years BP, *i.e.* during the late Pleistocene (PAULISSEN & VERMEERSCH 1989). It is likely (but, admittedly, nothing more than that) that the "fish trap" motifs date from the time range between about 13,000-12,000 and 7000 ^{14}C years BP.

5. Meaning and Motivation of Rock Art

If the El-Hosh curvilinear designs are indeed representations of early fish traps, why were they executed? What, in particular, was the motivation of the makers of this rock art?

A first point to consider is the fact that such curvilinear designs are extremely rare in the rock art of the Nile Valley. Among the many thousands of rock drawings which are known from Upper Egypt and Lower Nubia, only one specimen, recorded at a rock art site in the mainland area of the second cataract, can with certainty be related to the drawings under discussion (HELLSTROM 1970). Evidently, fish trap motifs are strictly confined to specific geographical areas.

The unusual term "fish hunters" in the title of this paper is a measured pun. It refers to a well-known Australian aboriginal phenomenon, namely the "moth hunters" (FLOOD 1980, 1988). The annual, massive summer migration of edible moths from the inland plains to the Australian Alps was the occasion for large gatherings of different friendly tribes. It is quite conceivable and ethnographically plausible that the area of El-Hosh was also the location of a seasonal congregation of people who came here at the time of the inundation (from June to September) to perform concerted fishing activities, and quite possibly, associated ceremonies and rituals, including the creation of rock art. As was the case in Australia, there may well have been a very close link in Egyptian prehistory between the management of certain food resources and the holding of initiation and other ceremonies.

It is, of course, extremely difficult to conceive what may have been the symbolic added value (if any) of the fish trap designs. Even if these images represent trivial objects, their function and meaning in the general context of the Nile Valley rock art were not necessarily mundane. In this particular case I think it may tentatively be suggested that these drawings relate to special ritual techniques that had to be observed in order to increase the efficiency of fishing gear and to secure a "miraculous draught of fishes". Many relics of such opportunistic rites, addressed to benevolent gods and powers beyond man, persist today, even in highly developed, sophisticated fisheries (VON BRANDT 1984).

6. The 2004 Archaeological Investigations

For lack of archaeological surveys and excavations, very little is known about prehistoric human settlement in this part of the Nile Valley. It is therefore difficult to ascertain whether the El-Hosh "fish trap" petroglyphs and associated scenery are of late Palaeolithic or early Neolithic/Predynastic vintage.

With the intention to recover archaeological traces of the people responsible for the creation of the archaic rock art repertoire at El-Hosh, several soundings were executed at the site of Gebelet Yussef in March-April 2004. Three of the four test trenches were made at shelter-like overhangs in the vicinity of rock art panels. Unfortunately, the shallow deposits in these shelters (0.5 m or less) were thoroughly disturbed (moreover, several of them had recently been used as onion cellars) and no archaeological material was found *in situ*. The finds, mainly ceramics, indicate that the site of Gebelet Yussef was frequented throughout the Predynastic and early Pharaonic periods. The most recent ceramics probably belong to the Second Intermediate Period (*c.* 1600 BC, "pan-grave" culture?). The oldest objects found are probably of Badarian or Naqada I vintage (*c.* 4000 BC?). Traces of still older occupation phases, which could be linked to the pre-7th millennium rock art repertoire, were not found.

In addition, a number of circular stone structures were investigated at the southern extremity of Gebelet Yussef. On the basis of the rough ceramics (often quartz- or calcite-tempered) found in and near these constructions, these are probably "Bedouin" and/or "Nubian" in nature. Their function and age remain unknown, although the presence of a floor in tamped earth with lots of straw inclusions in one of them seems to indicate that they have been (re-)used as stables fairly recently. To our surprise, one of these structures revealed an intact tomb, dug into the bedrock (with a depth of *c.* 0.75 m) (fig. 10). This tomb is

Fig. 10. — Intact tomb of Naqada IIC age (*c.* 3500-3400 BC) discovered below a circular "Bedouin" stone structure at the southern extremity of Gebelet Yussef.

Fig. 11. — "Decorated" vase from the Naqada IIC tomb at Gebelet Yussef (height: 12.2 cm).

clearly of Naqada IIC age (*c*. 3500-3400 BC) and contained a skeleton and a number of grave goods including two small "rough" jars, two large "red-polished" bowls, and a superb "decorated" vase (fig. 11). The latter item is decorated with boats, human figures and birds (flamingos or ostriches) (fig. 12). The deceased faced west and was buried head south in a contracted position, the hands covering the face. Below the skeleton lay several well-preserved fragments of reed matting. Leather fragments (from a bag?) were found near the hands. According to a preliminary anthropological analysis (by Dr Caroline Polet of the Royal Belgian Institute of Natural Sciences in Brussels), the skeleton is probably that of a female aged between forty and fifty and with a stature of about 1.55-1.60 m. It is currently unknown whether or not this tomb indicates the location of a Naqada II burial ground. A few Predynastic cemetery sites have previously been reported from the area, but none has ever been properly investigated (Hendrickx & van den Brink 2001).

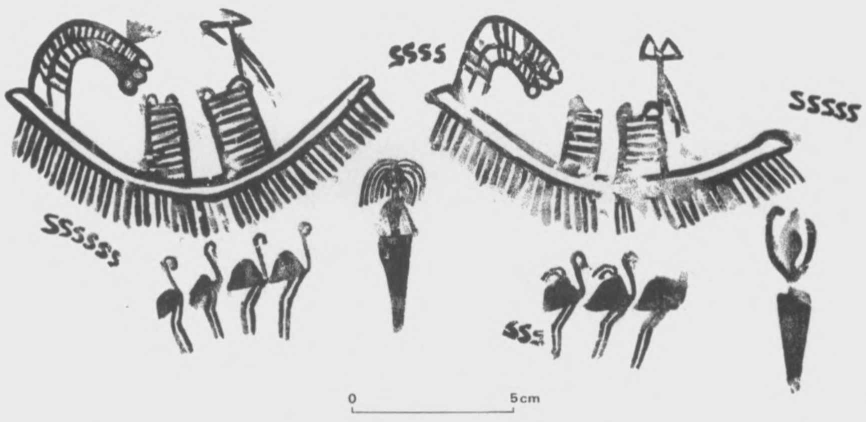


Fig. 12. — Designs on the "decorated" vase from the Naqada IIC tomb at Gebelet Yussef (tracing: I. Regulski).

7. Conclusion and Prospects

The rock art of El-Hosh is extremely important due to its extreme antiquity and anteriority to all other graphic manifestations in the Nile Valley. Notwithstanding the fact that its precise archaeological context remains obscure, it allows us to document a cultural-artistic phase in Egyptian history, evidently characterized by a rich and elaborate body of thought, which was hitherto completely unknown.

The area of El-Hosh has one of the highest densities of prehistoric and early historic rock drawings in Egypt. Because of their proximity to human settlement and newly constructed roads, many of the rock art sites are seriously endangered. Evidently, the research carried out in the scope of this project has adequately documented only part of rock art. Further recording of known sites is therefore an absolute necessity. Surveying of the El-Hosh area in March-April 2004 has also led to the discovery of several new rock art localities with an archaic repertoire of drawings. The most remarkable accomplishment in this field was the discovery of a new petroglyph locality at the southernmost tip of Abu Tanqurah Bahari. This locality shows several images of bovids executed in a "Franco-Cantabrian, Lascaux-like" naturalistic style (fig. 13). They are quite different from the stylized cattle representations in "classical" Predynastic iconography of the 4th millennium BC. On the basis of patination and weathering, these bovid representations are definitely extremely ancient (possibly late Palaeolithic or early Neolithic?). They are comparable to similar bovid images that have been discovered in 1962-63 on the opposite bank of the Nile, in the Gebel Silsila area (Smith 1965, 1985). Some of the bovid representations at Abu Tanqurah Bahari

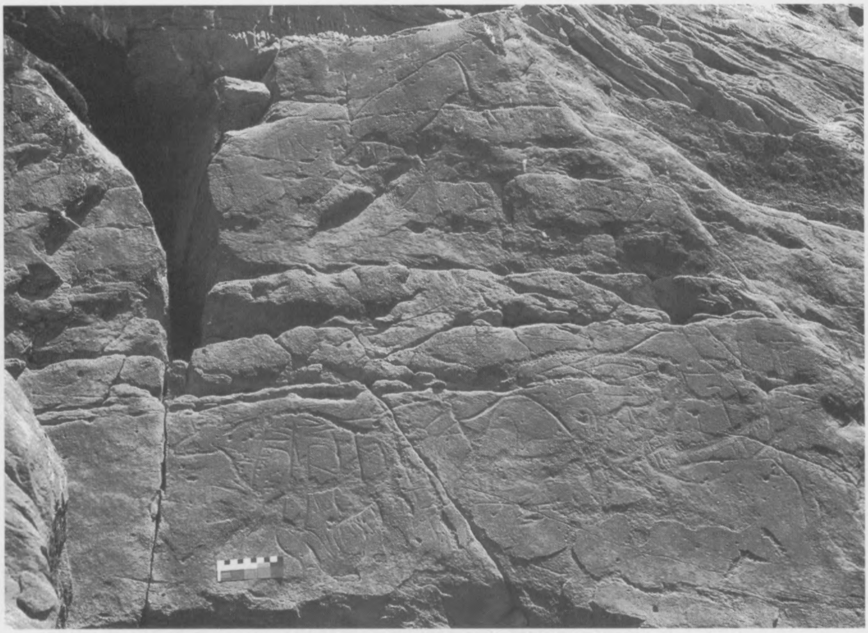


Fig. 13. — Extremely ancient drawings of bovids at the newly discovered rock art locality (Locality 11) at Abu Tanqurah Bahari.

are superimposed over still older images, possibly "steatopygous" anthropomorphic figures (again analogous to similar images discovered in the Gebel Silsila area; see Smith 1968). Further research at this remarkable locality and other promising sites in the area will be continued in the autumn of 2005.

ACKNOWLEDGEMENTS

I thank W. Claes (RMAH), B. Demarsin (*Provinciaal Gallo-Romeins Museum*, Tongeren), M. De Dapper (*Universiteit Gent*), D. Depraetere (*Katholieke Universiteit Leuven*), M. Helmy (*Katholieke Universiteit Leuven*), M. Ismail (Cairo University), E. Marchi (Archaeological Cooperative "Footsteps of Man", Cerveno), R. Mommaerts (RMAH), I. Regulski (*Katholieke Universiteit Leuven*), and A. Watchman (Australian National University) for their collaboration in field activities. J. Southon (Center for AMS of Lawrence Livermore National Laboratory) for processing the El-Hosh samples. The Egyptian Supreme Council of Antiquities for granting permission to conduct research at El-Hosh. Funding was provided by the National Geographic Society (grant 6109-98) and the Fund for Scientific Research – Flanders (grants 1.5.404.98 and 1.5.002.03). In addition, A. Watchman was supported by an Australian Research Fellowship. Special thanks also to S. Ikram (American University in Cairo) for commenting upon an earlier draft of this contribution.

NOTE

[1] Calendar dates and radiocarbon dates are written here in line with international convention. For calendar dates BC is used. Uncalibrated radiocarbon dates are expressed as ^{14}C years BP (before present). For calibrated radiocarbon dates, the term cal BC is used.

REFERENCES

BOULENGER, G. A. 1907. Zoology of Egypt: the Fishes of the Nile. — London, Hugh Rees Ltd, LI + 578 pp.

BREWER, D. J. & FRIEDMAN, R. F. 1989. Fish and Fishing in Ancient Egypt. — Warminster, Aris & Phillips, 109 pp.

CERVICEK, P. 1974. Felsbilder des Nord-Etbai, Oberägyptens und Unternubiens. — Wiesbaden, Franz Steiner Verlag, 229 pp.

CHESTER, G. I. 1892. On archaic engravings on rocks near Gebel Silsileh in Upper Egypt. — *The Archaeological Journal*, **49**: 120-130.

DEACON, J. 1984. Later Stone Age people and their descendants in Southern Africa. — *In:* KLEIN, R. G. (Ed.), Southern African Prehistory and Paleoenvironments. Rotterdam and Boston, A.A. Balkema, pp. 221-328.

FLOOD, J. 1980. The Moth Hunters. Aboriginal Prehistory of the Australian Alps. — Canberra, Australian Institute of Aboriginal Studies, 388 pp.

FLOOD, J. 1988. Archaeology of the Dreamtime. — Honolulu, University of Hawaii Press, 288 pp.

HELLSTROM, P. 1970. The Rock Drawings (The Scandinavian Joint Expedition to Sudanese Nubia, 1). — Stockholm, Scandinavian University Books, 238 pp.

HENDRICKX, S. 1999. La chronologie de la préhistoire tardive et des débuts de l'histoire de l'Egypte. — *Archéo-Nil*, **9**: 13-81.

HENDRICKX, S. & VAN DEN BRINK, E. C. M. 2001. Inventory of Predynastic and Early Dynastic cemetery and settlement sites in the Egyptian Nile Valley. — *In:* VAN DEN BRINK, E. C. M. & LEVY, T. E. (Eds.), Egypt and the Levant. Interrelations from the 4th through the Early 3rd Millennium BCE. London/New York, Leicester University Press, pp. 346-398.

HERMAN, O. 1901. Die Fängigkeit der Fischzäune und Fischreusen. — *Mitteilungen der Anthropologischen Gesellschaft in Wien*, **31**: 38-51.

HUYGE, D. 1998a. Possible representations of Palaeolithic fish-traps in Upper Egyptian rock art. — *Rock Art Research. Journal of the Australian Rock Art Research Association*, **15**: 3-11.

HUYGE, D. 1998b. Egypt's oldest 'art'? The petroglyphs of El-Hosh. — *Egyptian Archaeology. Bulletin of the Egypt Exploration Society*, **13**: 34-6.

HUYGE, D. 1999. El-Hosh revisited. — *Rock Art Research. Journal of the Australian Rock Art Research Association*, **16**: 51-52.

HUYGE, D., DE DAPPER, M., DEPRAETERE, D., ISMAIL, M., MARCHI, E., MOMMAERTS, R., REGULSKI, I. & WATCHMAN, A. 1998. Hilltops, silts, and petroglyphs: the fish hunters of El-Hosh (Upper Egypt). — *Bulletin des Musées royaux d'Art et d'Histoire*, **69**: 97-113.

HUYGE, D., WATCHMAN, A., DE DAPPER, M. & MARCHI, E. 2001. Dating Egypt's oldest 'art': AMS ^{14}C age determinations of rock varnishes covering petroglyphs at El-Hosh (Upper Egypt). — *Antiquity*, **75**: 68-72.

MYERS, O. H. 1958. 'Abka re-excavated. — *Kush*, **6**: 131-141.

PAULISSEN, E. & VERMEERSCH, P. M. 1989. Le comportement des grands fleuves allogènes: l'exemple du Nil saharien au Quaternaire supérieur. — *Bulletin de la Société géologique de France*, **8** (5-1): 73-83.

PAULISSEN, E., VERMEERSCH, P. M. & VAN NEER, W. 1985. Progress report on the late Palaeolithic Shuwikhat sites (Qena, Upper Egypt). — *Nyame Akuma*, **26**: 7-14.

SAHRHAGE, D. 1998. Fischfang und Fischkult im alten Ägypten. — Mainz, Philipp von Zabern, 174 pp.

SERJEANT, R. B. 1968. Fisher-folk and fish-traps in Al-Bahrain. — *Bulletin of the School of Oriental and African Studies*, **31**: 486-514.

SMITH, P. E. L. 1967. A preliminary report on the recent prehistoric investigations near Kom Ombo, Upper Egypt. — *In*: Fouilles en Nubie (1961-1963). Le Caire, Service des Antiquités de l'Egypte, pp. 195-208.

SMITH, P. E. L. 1968. Le "Veneri" di Kom-Ombo. — *Bollettino del Centro Camuno di Studi Preistorici*, **4**: 162.

SMITH, P. E. L. 1985. An enigmatic frieze from Upper Egypt: a problem in Nilotic rock art. — *In*: LIVERANI, M., PALMIERI, A. & PERONI, R. (Eds.), Studi di paletnologia in onore di Salvatore M. Puglisi. Roma, Università di Roma "La Sapienza", pp. 359-368.

THOMAS, D. S. G. 1997. Arid Zone Geomorphology. — Chichester, John Wiley & Sons, 713 pp.

TUNIZ, C. & WATCHMAN, A. 1994. The ANTARES AMS spectrometer. Accelerators and lasers for dating rock art in Australia. — *Rock Art Research. Journal of the Australian Rock Art Research Association*, **11**: 71-73.

VAN ELSBERGEN, M. J. 1997. Fischerei im Alten Agypten. Untersuchungen zu den Fischfangdarstellungen in den Gräbern der 4. bis 6. Dynastie (Abhandlungen des Deutschen Archäologischen Instituts Kairo. Agyptologische Reihe, 14). — Berlin, Achet-Verlag, XXII + 319 pp.

VERMEERSCH, P. M., PAULISSEN, E. & VAN NEER, W. 1989. The late Palaeolithic Makhadma sites (Egypt): environment and subsistence. — *In*: KRZYZANIAK, L. & KOBUSIEWICZ, M. (Eds.), Late Prehistory of the Nile Basin and the Sahara. Poznan, Poznan Archaeological Museum, pp. 87-114.

VON BRANDT, A. 1984. Fish Catching Methods of the World. — Farnham (Surrey), Fishing News Books Ltd, 418 pp.

WATCHMAN, A. 2000. A review of the history of dating rock varnishes. — *Earth-Science Reviews*, **49**: 261-277.

WINKLER, H. A. 1938. Rock-Drawings of Southern Upper Egypt I. — London, The Egypt Exploration Society, 44 pp.

WINKLER, H. A. 1939. Rock-Drawings of Southern Upper Egypt II. — London, The Egypt Exploration Society, 40 pp.

Classe des Sciences naturelles et médicales

Klasse voor Natuur- en Geneeskundige Wetenschappen

Bull. Séanc. Acad. R. Sci. Outre-Mer
Meded. Zitt. K. Acad. Overzeese Wet.
51 (2005-3) : 253-263

Le séisme géant de subduction de Sumatra-Andaman du 26 décembre 2004: leçons pour une alerte efficace des tsunamis *

par

Thierry CAMELBEECK **

MOTS-CLES. — Tremblements de terre; Subduction; Tsunami; Magnitude; Système d'alerte.

RESUME. — Le tremblement de terre de Sumatra-Andaman du 26 décembre 2004 a provoqué une rupture de la limite sous-marine entre la plaque indienne et la micro-plaque birmane sur une longueur de 1 300 km. C'est le plus grand tremblement de terre (M_W = 9,3) de ces quarante dernières années dans le monde et le premier de cette importance qui ait pu être étudié avec des équipements sismiques modernes. Nous présentons une synthèse des caractéristiques de la source de cet événement. Sa conséquence principale a été le tsunami qui a dévasté les côtes de l'océan Indien, causant la mort de plus de 226 000 personnes. Cette catastrophe est tragique parce qu'une partie de ses conséquences aurait pu être évitée par un système d'alerte au tsunami approprié. Le 28 mars 2005, un autre séisme géant de subduction s'est produit dans la même zone de subduction, mais au sud de la limite de plaque affectée par celui du 26 décembre 2004. Ce tremblement de terre de magnitude M_W = 8,7 n'a généré qu'un petit tsunami dans l'océan Indien. A partir de cet exemple, nous discutons les problèmes posés par l'évaluation rapide du caractère tsunamigène des tremblements de terre pour le déclenchement d'une alerte efficace. En particulier, nous discutons les difficultés d'évaluer correctement la magnitude d'un tremblement de terre de cette importance dans un délai qui soit compatible avec un système d'alerte.

TREFWOORDEN. — Aardbevingen; Subductie; Tsunami; Magnitude; Waarschuwingssysteem.

SAMENVATTING. — *De Sumatra-Andaman mega-overschuivingsaardbeving van 26 december 2004: lessen voor een doeltreffend tsunamiwaarschuwingssysteem.* — De Sumatra-Andaman aardbeving van 26 december 2004 heeft een onderzeese breukverplaatsing veroorzaakt tussen de Indische plaat en de Birmaanse microplaat over een lengte van 1 300 km. Het is de grootste aardbeving (M_w = 9,3) in de wereld van de

---

* Communication présentée à la séance commune des trois Classes tenue le 19 avril 2005. Décision de publication prise les 22 et 24 novembre 2005. Texte definitif reçu le 23 décembre 2005.

** Chef de la section Séismologie, Observatoire Royal de Belgique, av. Circulaire 3, B-1180 Bruxelles (Belgique).

afgelopen veertig jaar en de eerste van die omvang die met moderne seismische technieken bestudeerd kan worden. Wij brengen een synthese van de karakteristieken van de bron van deze gebeurtenis. Het belangrijkste gevolg is de tsunami die de kust van de Indische Oceaan heeft verwoest en meer dan 226 000 doden heeft geëist. Deze ramp was tragisch omdat een deel van haar gevolgen had kunnen worden vermeden door een aangepast tsunamiwaarschuwingssysteem. Op 28 maart 2005 deed zich in dezelfde subductiezone, maar ten zuiden van de grens van de door deze van 26 december 2004 getroffen plaats, een andere mega-overschuivingsaardbeving voor. Deze aardbeving met magnitude Mw = 8,7 heeft slechts een kleine tsunami veroorzaakt in de Indische Oceaan. Vertrekkend van dit voorbeeld bespreken we de problemen van een snelle evaluatie van een aardbeving met tsunamigevaar om een doeltreffend alarm in werking te stellen. Meer bepaald bespreken wij de moeilijkheden om de magnitude van zo'n grote aardbeving correct te bepalen in de beperkte tijdspanne die nodig is voor een alarmprocedure.

Keywords. — Earthquakes; Subduction; Tsunami; Magnitude; Warning System.

Summary. — *The December 26, 2004 Sumatra-Andaman Megathrust Earthquake: Lessons for a Tsunami Warning System.* — The December 26, 2004 Sumatra-Andaman earthquake ruptured the seafloor boundary between the Indian Plate and the Burmese Microplate for a stretch of 1,300 km. It is the largest earthquake ($M_w = 9.3$) in the past forty years and the first of this importance which can be studied with modern seismic equipment. A synthesis of the characteristics of the source of this event is presented. Its main consequence was the tsunami which devastated the Indian Ocean coasts and took more than 226,000 lives. The event was tragic because a part of its consequences could have been avoided by an appropriate tsunami warning system. On 28 March 2005, another megathrust earthquake occurred in the same subduction area, but south of the plate boundary affected by the one of 26 December, 2004. This earthquake with magnitude Mw = 8,7 brought about only a small tsunami in the Indian Ocean. Starting from this example, the problems of evaluating rapidly the tsunamogenic character of an earthquake for the triggering of an effective alarm, are discussed. In particular, the difficulties in evaluating correctly the magnitude of such a large earthquake with a delay compatible with the alert are discussed.

1. Les tremblements de terre de Sumatra des 26 décembre 2004 et 28 mars 2005

Le tremblement de terre du 26 décembre 2004 s'est produit à la limite entre la plaque indo-australienne et la plaque birmane, qui fait partie de la plaque eurasiatique (fig. 1). Ces plaques se déplacent l'une vers l'autre à une vitesse de 5 à 6 cm/an. Comme ce rapprochement entre les plaques a lieu obliquement par rapport à la limite des plaques, le mouvement se répartit entre la subduction de la plaque indo-australienne sous la plaque de la Sonde, le long de la fosse de la Sonde, et un mouvement de faille décrochant dextre le long de la faille de Sumatra, qui s'étend tout au long de l'île de Sumatra. Le tremblement de terre s'est produit dans le plan de subduction et est la conséquence d'un relâchement brusque des tensions qui s'étaient accumulées pendant des siècles, à la suite du mouvement continu des plaques. L'analyse des enregistrements par les réseaux sismiques globaux a permis (LAY *et al.* 2005) de déterminer que le déplacement relatif des plaques a été en moyenne de 10 m pour une rupture d'une longueur de 1 300 km (la largeur du plan de faille étant d'environ 200 km). Le mouvement du front de rupture a été rapide avec une vitesse classique de 2,5 km/s et le glissement a été de grande amplitude (plus de 20 m à certains endroits) dans la région la plus au sud, proche de Sumatra, tandis que plus vers le nord, le long des îles Nicobar et Andaman, la vitesse de rupture a été beaucoup plus faible (0,5 km/s). Le processus de rupture global a duré au moins 1 000 s, mais a pu durer jusqu'à 3 600 s. La magnitude du tremblement de terre a été évaluée à M_W = 9,3.

Tout comme le séisme du 26 décembre 2004, le séisme du 28 mars 2005 a été qualifié de *megathrust*, de par le type de mouvement et au vu de la taille également exceptionnelle, bien que beaucoup plus réduite, de la surface de faille qui a bougé durant le tremblement de terre. Ce séisme s'est produit en dehors de la zone de rupture du séisme du 26 décembre 2004 (fig. 1) et ne peut donc pas être considéré comme «réplique» au sens strict. Cependant, le tremblement de terre de décembre 2004 a causé un accroissement des contraintes dans ce segment de

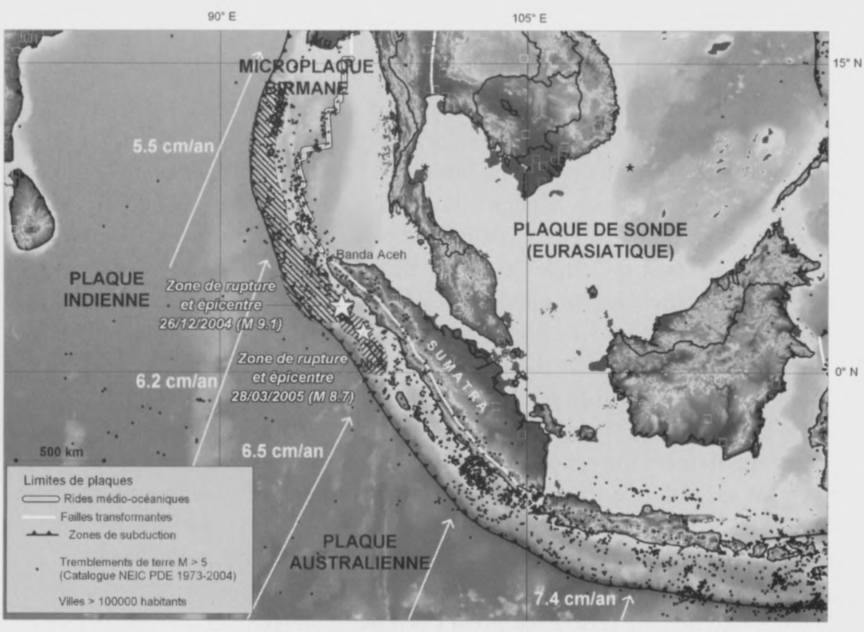


Fig. 1. — Contexte tectonique et dimension de la source des tremblements de terre du 26 décembre 2004 et 28 mars 2005 à Sumatra.

faille voisin, provoquant l'initiation de la rupture. Avec une magnitude de 8,7 M_W, l'énergie totale «dégagée» par ce tremblement de terre est environ trois fois moindre que lors de celui du 26 décembre 2004. La longueur de la zone de rupture est estimée à environ 350 km avec un déplacement maximal de 12 m (5 m en moyenne).

2. Dans quelle mesure un séisme peut-il générer un tsunami?

Le tremblement de terre du 26 décembre 2004 a provoqué le tsunami le plus dramatique de l'histoire récente de notre planète. Il a en effet causé la mort d'environ 226 000 personnes le long des côtes de l'océan Indien (Ozer & de Longueville 2005). Une alerte efficace aurait probablement permis de sauver de nombreuses vies humaines. Malheureusement, aucun système de ce type n'était en place dans la région. L'exemple du tremblement de terre du 28 mars 2005 pose cependant la question de la possibilité de réellement mettre en œuvre un système d'alerte suffisamment efficace. Le Centre d'Alerte des Tsunamis (du Pacifique) a, dans le cas du séisme du 28 mars 2005, émis une alerte transmise à tous les pays ayant des côtes dans l'océan Indien, mais seul un petit tsunami s'est produit. Sur l'île de Simeuluei, le port et l'aéroport ont été endommagés par des vagues de 3 m de haut tandis que des eaux d'une hauteur de 2 m se sont abattues sur la côte occidentale de l'île de Nias et d' 1 m de haut sur certaines parties des côtes occidentales de Sumatra. A plus grande distance, des marégraphes ont aussi enregistré des oscillations du niveau de la mer, de l'ordre de 5 à 20 cm, entre autres aux îles Maldives, au Sri Lanka et à l'île Cocos, près de l'Australie.

On a parlé de succès dans les médias parce que les populations avaient été évacuées des bords de mer dans de nombreuses régions du pourtour de l'océan Indien et qu'il n'y avait eu aucune victime. En fait, le système d'alerte a été en erreur et a montré toutes ses limitations. L'aspect positif est toutefois le fait que les autorités locales, régionales et nationales dans de nombreux pays ont apparemment réagi efficacement une fois que l'alerte a été déclenchée. Cela se passait trois mois après la catastrophe du 26 décembre 2004. Qu'en sera-t-il dans quelques années ou dizaines d'années?

L'analyse des conséquences de ces deux tremblements de terre majeurs nous indique clairement que la mise au point d'une alerte efficace nécessite en premier lieu une meilleure compréhension de la relation entre la cause, le tremblement de terre, et sa conséquence, le tsunami. Il est important de noter ici que les tremblements de terre ne sont pas la seule source possible de tsunamis et que les avalanches sous-marines ainsi que l'effondrement d'édifices (ou de parties d'édifices) volcaniques sont également la source de certains tsunamis.

Un tremblement de terre peut être à l'origine d'un tsunami pour deux raisons. La première est liée à la source du séisme et résulte du déplacement permanent très rapide du fond océanique associé. D'autre part, l'accumulation rapide des sédiments sur les fonds marins en font des masses importantes instables, même sur des pentes très faibles. Les forts mouvements du sol générés par un tremblement de terre peuvent déclencher des avalanches sous-marines dont la conséquence peut être des mouvements d'eau importants.

Ainsi, le séisme majeur du 28 mars 2005, malgré sa magnitude plus faible que celui du 26 décembre 2004, correspondant à une surface de faille (et donc du plancher océanique) et un mouvement plus petits, aurait pu causer un grand tsunami. Plusieurs paramètres de la source du séisme peuvent expliquer en partie que seul un petit tsunami ait été généré:

— Le déplacement vertical, ou soulèvement, du plancher océanique était plus petit (en moyenne 1 m) que lors du tremblement de terre du 26 décembre 2004 (données *US Geological Survey* le jour du séisme).
— Le soulèvement maximal du plancher océanique se trouvait sous les îles situées au large de la côte occidentale de Sumatra, où la profondeur de la mer est bien moindre (environ 200 m) qu'à l'endroit de la zone de rupture du séisme de décembre (1 500 à 4 000 m). Le volume d'eau déplacé a été, en conséquence, beaucoup plus faible.
— La vitesse de propagation le long de la zone de rupture peut avoir été plus lente que lors de la rupture initiale en décembre 2004.

Il est vraisemblable également que cette partie de l'océan Indien n'ayant plus subi d'événements de magnitude supérieure à 7,5 depuis près d'un siècle, en tout cas dans la région où s'est initiée la rupture, le séisme du 26 décembre 2004 a pu provoquer des avalanches sous-marines importantes, qui ont grandement contribué au tsunami gigantesque observé. Lors du séisme du 28 mars 2005, les grandes zones instables potentielles n'existaient plus et peu de glissements sous-marins se seraient produits. C'est une hypothèse tout à fait plausible, mais qui ne peut être vérifiée que par une observation intensive des fonds sous-marins de la région.

Dans le futur, l'étude scientifique de ces deux tremblements de terre majeurs et de leurs conséquences devrait faire progresser notre connaissance sur la relation entre les tremblements de terre affectant le plancher océanique et la genèse des tsunamis.

3. De la difficulté d'une alerte au tsunami: évaluation rapide de la grandeur des tremblements de terre

Un quotidien belge titrait justement «Le degré zéro de l'alerte» (Delbecq *et al.* 2005) et décrivait fort à propos la chronologie des failles du système d'alerte international des tsunamis lors du séisme du 26 décembre 2004: «D'abord une magnitude sous-estimée, puis un premier bulletin d'Hawaï focalisé sur le Pacifique et écartant le risque de tsunami, ...». Je cite ces deux premières «faiblesses» du système parce qu'elles concernent directement l'aspect scientifique de l'alerte. Ces manquements du système d'alerte résultent d'abord de la difficulté d'évaluer quasiment en temps réel la grandeur de la source de tels tremblements de terre et ensuite du fait qu'une alerte rapide ne peut être déclenchée que par l'utilisation de critères simples telles la magnitude du tremblement de terre et la localisation de son épicentre (en mer ou sur terre).

La grandeur du séisme est un paramètre important dans l'évaluation du potentiel tsunami-gène d'un tremblement de terre en raison des dimensions de la surface de faille affectée et du mouvement relatif entre les deux plaques lithosphériques concernées. Dans le cas d'une zone de subduction, comme à Sumatra, cette dernière grandeur se répercute directement en surface de fond océanique déplacé et en mouvement de la colonne d'eau au-dessus de la partie du fond océanique déplacé. La localisation du tremblement de terre et son extension dans l'océan sont donc des éléments importants à considérer comme son mécanisme au foyer, définissant le type de mouvement lors du séisme. Nous avons vu au paragraphe précédent que la géologie et la topographie des fonds océaniques jouent un rôle essentiel parce qu'une conséquence indirecte du tremblement de terre peut être le déclenchement de glissements sous-marins gigantesques potentiellement responsables de tsunamis.

Un système d'alerte qui ne prenne en considération que les caractéristiques du tremblement de terre est donc loin d'être optimal. L'idéal serait de surveiller en permanence les océans de manière à y détecter la propagation d'éventuels tsunamis. Actuellement, quelques points de mesure existent dans l'océan Pacifique; ils ne permettent que de confirmer ou infirmer une alerte. Une telle surveillance demandera(it) du temps pour être opérationnelle et nécessitera(it) des moyens techniques et un coût gigantesque. Tout en soutenant que des moyens de recherche doivent être attribués à l'étude des océans, je pense qu'étant donné le niveau de risque lié aux tsunamis, faible comparé au risque sismique, plus de moyens financiers devraient être attribués à la prévention, à l'organisation de la réponse des autorités à de tels événements et à des systèmes d'alerte plus locaux, comme ceux existant au Japon.

Le système d'alerte actuel (pour l'océan Pacifique) est basé sur la définition de critères simples comme la magnitude et la localisation du tremblement de terre. La raison principale est la nécessité de fournir un message d'alerte aussi vite que possible après le séisme pour que les mesures appropriées de protection puissent être mises en œuvre avant que les vagues du tsunami n'atteignent les côtes. La suite du paragraphe illustrera certaines des difficultés rencontrées par les scientifiques pour définir ces paramètres simples, en prenant comme exemple le séisme du 26 décembre 2004.

Directement après l'occurrence du tremblement de terre du 26 décembre 2004, celui-ci n'a pas été considéré comme un événement susceptible d'avoir les conséquences néfastes que nous connaissons. La raison principale est que sa magnitude a d'abord été évaluée à $M_w = 8{,}0$ alors que la grandeur finale déterminée trois mois après l'événement à partir de l'étude des modes normaux de vibration de la Terre est $M_W = 9,3$.

Ceci illustre la difficulté d'évaluer correctement en temps réel la magnitude de tels séismes. Dans le tableau 1, nous reprenons la chronologie des différents faits liés à l'alerte au tsunami à partir de l'instant d'initiation de la rupture du tremblement de terre. Les données figurant dans ce tableau sont reprises de Park *et al.* (2005), Vanneste & Van Hoolst (2005) et des différents mails d'alerte et informations reçus à la section de sismologie de l'Observatoire Royal de Belgique.

Tableau 1

Chronologie des faits liés à l'alerte au tsunami lors du séisme du 26 décembre 2004

Heure	Evénement
0h00m	heure origine du séisme
0h03m	l'analyste du centre d'alerte des tsunamis à Hawaï observe les premiers signaux sismiques
0h06m03s	les ondes P sont enregistrées en Australie à une distance de 34°
0h08m	alerte automatique générée par le centre d'alerte des tsunamis à Hawaï
0h08m20s	la rupture rapide du tremblement du terre se termine (460s)
0h10m	le NEIC (United States National Earthquake Information Center) fournit une alerte
0h11m	le centre d'alerte des tsunamis à Hawaï fournit une première évaluation de la magnitude $M_{WP} = 8,0$
0h13m33s	les ondes P atteignent l'Alaska
0h15m	le tsunami atteint la côte la plus proche à Sumatra
	le centre d'alerte des tsunamis à Hawaï dissémine son premier bulletin d'information au tsunami en se basant sur la magnitude $M_{WP} = 8,0$
0h17m	NEIC donne en solution automatique: $m_b = 6,2$
	l'analyste du NEIC constate l'événement
0h18m50s	les ondes P atteignent la côte ouest des Etats-Unis (distance de 121°)
0h40m	NEIC calcule par inversion de routine du tenseur moment: $M_w = 8,2$
0h45m	le centre d'alerte des tsunamis détermine $M_w = 8,5$
1h30m	les ondes de surface atteignent l'antipode
1h45m	le tsunami atteint la Thaïlande et le Sri Lanka
2h05m	Harvard Automatic CMT détermine automatiquement $M_w = 8,9$
19h03m	Harvard CMT revu à Mw = 9,0
Mars 2005	après étude des modes propres de la Terre: Mw = 9,3

Alors qu'une localisation relativement correcte d'un tremblement de terre lointain peut être obtenue quinze à vingt minutes après l'occurrence du séisme à partir de la mesure des temps d'arrivée de l'onde P dans les stations situées à moins de 100° de l'épicentre, l'évaluation de la magnitude est beaucoup plus délicate.

La mesure la plus adéquate de la grandeur d'un tremblement de terre est le **moment sismique M_0** qui est directement relié aux dimensions de la faille le long de laquelle la rupture s'est propagée et à la grandeur du mouvement relatif provoqué par le séisme:

$$M_0 = \mu \, L \, W \, D$$

où μ est la rigidité moyenne dans la région focale, L et W sont respectivement la longueur et la largeur de la faille tandis que D est le mouvement relatif (glissement) moyen entre les deux blocs crustaux séparés par la faille.

En observant les ondes sismiques à des longueurs d'ondes plus grandes que les dimensions de la faille affectée, la source des séismes peut être supposée ponctuelle et représentée par un double couple de forces dont le moment résultant est nul. Le moment d'un de ces couples est précisément le moment sismique. Une bonne détermination du moment sismique nécessite donc l'analyse des ondes sismiques qui ont des longueurs d'ondes supérieures aux dimensions de la faille. Le moment sismique des grands tremblements de terre est généralement déterminé par l'analyse des enregistrements sur les séismomètres à très longue période (100 s) (Harvard CMT – Dziewonski *et al.* 1981).

Plus empirique, le concept de **magnitude** est basé sur la mesure du déplacement maximal du sol mesuré sur les séismogrammes des différentes stations ayant enregistré un tremblement de terre, l'atténuation de cette amplitude en fonction de la distance étant prise en considération.

La magnitude locale M_L est définie par la relation:

$$M_L = \log_{10} A(\Delta) - \log_{10} A_0(\Delta)$$

où

— $A(\Delta)$ est le déplacement maximal du sol en une station située à une distance Δ du foyer sismique.
— $A_0(\Delta)$ est le déplacement maximal prédéterminé pour un séisme de magnitude nulle. Cette fonction dépend de la région considérée.

La magnitude locale est utilisée pour déterminer la grandeur des séismes crustaux localisés à moins de 1 000 km de la station. Etant donné que les séismomètres utilisés ont une fréquence propre de 1 Hz, les fréquences des mouvements du sol utilisées pour la détermination de la magnitude sont donc toujours supérieures à 1 Hz.

Le concept a été étendu pour permettre d'évaluer la grandeur des tremblements de terre enregistrés à des distances supérieures à 1 000 km; deux échelles de magnitude sont particulièrement utilisées:

— m_b (magnitude d'ondes de volume) qui est déterminée à partir des ondes de volume P à 1 s de période;
— M_S (magnitude d'ondes de surface) qui est déterminée à partir des ondes de surface à 20 s de période.

Chaque échelle de magnitude a ses limitations. La principale est que pour des tremblements de terre dont la longueur de faille est supérieure à la longueur d'onde des ondes sismiques utilisées pour sa détermination, la valeur de la magnitude n'augmente plus de manière significative et tend asymptotiquement vers une valeur limite quelle que soit la dimension de la faille (m_b = 6,2 dans le

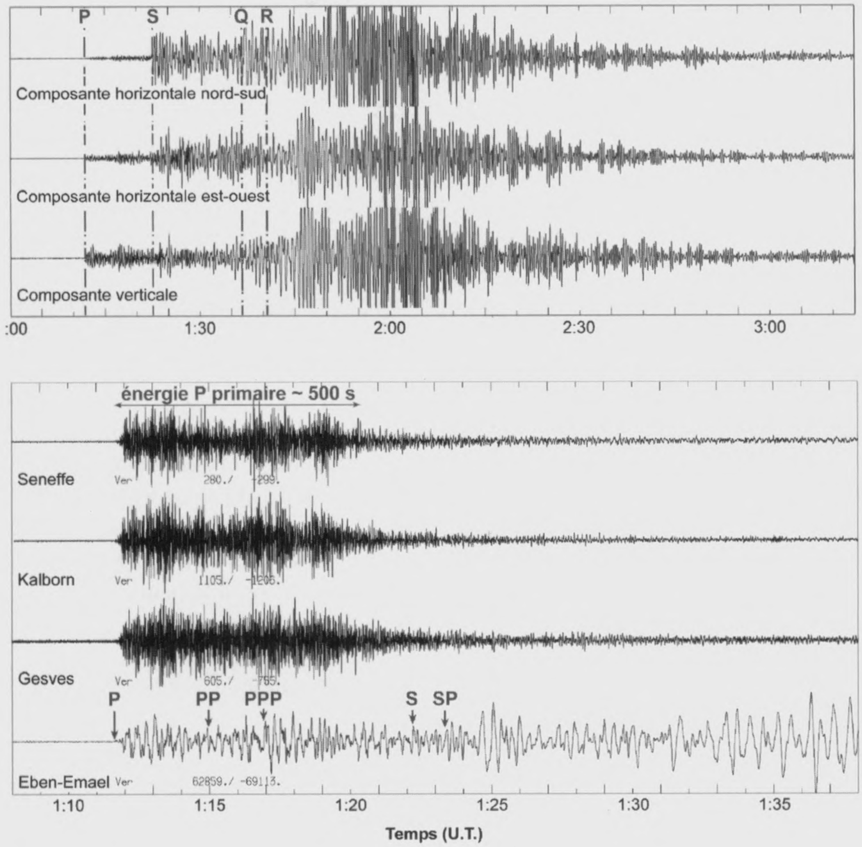


Fig. 2. — Enregistrements du séisme de Sumatra du 26 décembre 2004 par quelques stations du réseau sismique belge: (a) (image supérieure) trois composantes du mouvement du sol à la station «large-bande» de Rochefort. L'arrivée du début du signal des ondes de volume P et S ainsi que des ondes de surface Q et R est indiquée; (b) (image inférieure) enregistrement des ondes de volume sur la composante verticale du mouvement du sol dans les stations courtes-périodes de Seneffe, Kalborn (grand-duché de Luxembourg) et Gesves en parallèle avec la station à large bande d'Eben-Emael.

cas du séisme de Sumatra — voir tab. 1). Afin de donner une magnitude réellement représentative des mécanismes physiques, Kanamori (1977) a défini la magnitude M_W basée sur la valeur du moment sismique. Si le moment sismique (en N.m; Newton.mètre) est déterminé, on a: $M_W = 2/3 \log_{10} M_0 - 6.06$.

Pour obtenir une valeur représentative de la grandeur des sources sismiques pour les grands tremblements de terre, il est nécessaire de déterminer une valeur du moment sismique, ce qui ne peut se faire qu'en considérant les signaux à très basse fréquence dont les plus énergétiques (ondes de surface) arrivent tardivement dans les différentes stations sismiques du réseau global (fig. 2 (a)).

C'est la raison pour laquelle, dans le cas du séisme de Sumatra (tab. 1), il a fallu attendre 2h05m avant d'avoir une première détermination correcte du moment sismique (M_w = 8,9). Une analyse plus complète, dix-neuf heures après l'événement, a revu la magnitude à M_w = 9,0.

La magnitude de l'événement a finalement été fixée, trois mois après celui-ci, à M_w = 9,3 en utilisant les amplitudes des modes propres de vibration de la Terre. L'Observatoire Royal de Belgique a contribué à cette étude grâce aux enregistrements du gravimètre à supraconductivité de la station sismique de Membach (Park *et al.* 2005).

Evaluer rapidement la magnitude d'événements gigantesques est donc une question scientifique à l'ordre du jour. Une première réponse est de considérer les ondes P, premiers signaux qui arrivent dans les stations sismiques. Les sismogrammes à haute fréquence (fréquence supérieure à 1 Hz) contiennent en prédominance des ondes P rayonnées directement par la rupture du tremblement de terre avec peu d'interférence avec les ondes réfléchies à la surface de la Terre (PP, PPP, PS,...) ou les ondes S (comparer sur la fig. 2 (b) les enregistrements courtes-périodes avec celui à large bande). Cela signifie que ces ondes P à haute fréquence peuvent fournir une information sur le processus de rupture à la source du séisme. En supposant que la rupture des grands tremblements de terre se produit à vitesse constante le long d'une faille beaucoup plus longue que large, la surface de faille est proportionnelle à la durée du sismogramme.

L'analyse des données des stations du réseau sismique belge (fig. 2 (b)) indique que le processus de rupture a duré environ 500 s. Si on suppose une vitesse classique de propagation de la rupture entre 2 et 3 km/s, cela signifie que la rupture s'est étendue sur une longueur de 1 000 à 1 500 km, proche des 1 300 km déterminés par les analyses plus fines. En faisant des hypothèses sur la largeur de faille et les dimensions du glissement (en accord avec les lois d'échelle des séismes), il est possible d'évaluer grossièrement le moment sismique. Mon analyse est bien sûr rapide, mais il apparaît que c'est probablement un des seuls moyens pour obtenir une évaluation correcte de la source des séismes géants dans un délai de temps minimal.

4. Conclusions

La catastrophe du 26 décembre 2004 dans l'océan Indien n'était pas inattendue, contrairement à ce qui a été largement commenté après la catastrophe. Un tel phénomène est rare, mais il y avait déjà eu des précédents historiques. Les mesures de prévention existent généralement pour les phénomènes qui ont une période de retour courte. Par contre, elles sont inexistantes pour les phénomènes qui ont été effacés de la mémoire des populations. Nos sociétés sont de plus en plus vulnérables vis-à-vis des catastrophes naturelles et il me semble qu'un des aspects du développement durable serait justement de se préoccuper de ce genre d'événements et d'essayer par une action continue à long terme de diminuer leur futur impact sur l'environnement, les populations et l'économie. Les conséquences du tremblement de terre de Sumatra-Andaman et du tsunami qui s'en est suivi sont illustratives de ce manque de prévision et de précaution dans nos sociétés.

REMERCIEMENTS

Je remercie mes collègues de l'Observatoire Royal de Belgique qui ont participé activement durant les fêtes de fin d'année et en janvier 2005 à la collecte et à l'analyse des données du réseau sismique belge pour le séisme du 26 décembre 2004 et qui ont permis l'interprétation de ces données en termes de géodynamique. Michel Van Camp, par son étude des modes propres de vibration de la Terre, a contribué efficacement à l'article de Park *et al.* (2005) dans *Science,* tandis que Kris Vanneste, par ses nombreuses recherches bibliographiques, a permis d'illustrer l'activité sismique récente dans la région de Sumatra en relation avec les grands séismes historiques et la géologie récente.

BIBLIOGRAPHIE

Delbecq, D., Honorine, S., Prakash, P. & Masciarelli, A. 2005. Le degré zéro de l'alerte. — *La Libre Belgique* (17 janvier 2005), pp. 4-5.

Dziewonski, A., Chou, T. A. & Woodhouse, J. H. 1981. Determination of earthquake source parameters from waveform data for studies of global and regional seismicity. — *Journal of Geophysical Research*, **86**: 2825-2852.

Kanamori, H. 1977. The energy release in great earthquakes. — *Journal of Geophysical Research,* **82**: 2981-2987.

Lay, T., Kanamori, H., Ammon, C., Nettles, M., Ward, S., Aster, R., Beck, S., Bilek, S., Brudzinski, M., Butler, R., De Shon, H., Ekstrom, G., Satake, K. & Sipkin, S. 2005. The Great Sumatra-Andaman Earthquake of 26 December 2004. — *Science,* **20** (May 2005): 1127-1133.

Vanneste, K. & Van Hoolst, T. 2005. De tsoenami van 26 december 2004. — *Heelal,* **50** (8): 261-269.

Ozer, P. & de Longville, F. 2005. Tsunami en Asie du Sud-Est: retour sur la gestion d'un cataclysme naturel apocalyptique. — *Cybergi*, **321** (14 octobre 2005), http://www.cybergeo.presse.fr

Park, J., Song, T. A., Tromp, J., Okal, E., Stein, S., Roult, G., Laske, G., Kanamori, H., Davis, P., Berger, J., Braitenberg, C., Van Camp, M., Lei, X., Sun, H. & Xu, H. 2005. Long-period behavior of the 26 December 2004 Sumatra-Andaman from its excitation of Earth's free oscillations. — *Science*, **308** (5725): 1139-1144.

Bull. Séanc. Acad. R. Sci. Outre-Mer
Meded. Zitt. K. Acad. Overzeese Wet.
51 (2005-3) : 265-299

Buruli Ulcer: An Historical Overview with Updating to 2005 *

by

Pieter JANSSENS **, Stefaan PATTYN **, Wayne MEYERS *** &
Françoise PORTAELS **[1]

Foreword

Prof. P. G. Janssens died on 13 December 2005. Before he died and at the request of Prof. F. Portaels, he agreed to document his rich experience in the discovery of BU cases in Congo. He was the first person to bring to light the existence and importance of the disease to the Institute of Tropical Medicine (ITM), Antwerp, Belgium, where he was Director from 1957 until 1976.

Prof. P. G. Janssens, Baltimore MD, 5.9.1961

* Paper presented by S. R. Pattyn at the meeting of the Section of Natural and Medical Sciences held on 21 February 2006. Text received on 10 March 2006.

** Mycobacteriology Unit, Department of Microbiology, Institute of Tropical Medicine, Nationalestraat 155, B-2000 Antwerpen (Belgium).

**[1] Corresponding author; Mycobacteriology Unit, Department of Microbiology, Institute of Tropical Medicine, Nationalestraat 155, B-2000 Antwerpen (Belgium).

*** Department of Environmental and Infectious Diseases Sciences, Armed Forces Institute of Pathology, Washington DC (USA).

It is a great pleasure to pay homage to the medical field experience, and to the insight and vision of Prof. P. G. Janssens, for the timely recognition of the importance of such tropical diseases as BU.

This history, initially written by Prof. P. G. Janssens, has been supplemented by the field and laboratory experience of the three other authors, all of whom have dedicated themselves to the fight against BU in the field and on the bench, inspired mainly by the example of Prof. P. G. Janssens.

We also pay tribute to Prof. P. G. Janssens with this photograph taken at Baltimore in September 1961 by his friend Dr W. H. Feldman, another well-known scientist in the field of mycobacteriology.

SUMMARY. — The primary objectives of this review are to describe the early history of the discovery of Buruli Ulcer (BU) and to portray the pioneer scientists and patients involved, especially the role of the late Prof. P. G. Janssens in the discovery of the first cases in Congo. Prof. Janssens authored the early drafts of this article and the three co-authors updated the review through the year 2005. The earliest documentation of BU was in Australia in 1937, in tropical Africa in 1942 and in New Guinea during the 1950s.

Clinical and laboratory research on BU and its etiology (*Mycobacterium ulcerans*) was carried out in Africa under the arduous and stark circumstances that characterized the period of transition from colonial to national health services. Physicians in Africa were well acquainted with tropical phagedenic ulcers and were understandably the first to note that *M. ulcerans* infections, although having some similarities, were a disease apart. Scientists in Australia had ready access to both sophisticated laboratory facilities and BU patients and thus were able to contribute significantly to the early understanding of the disease and culture of the etiologic agent.

Over the past 10-15 years there has been a notable expansion of knowledge of the epidemiology and pathogenesis of BU. Today, for example, *M. ulcerans* is identified by phenotypic and genetic microbiologic tests.

Of the 30 countries reporting BU, cases have been confirmed microbiologically in 25 countries. Cases in the remaining 5 countries (Indonesia, Kiribati, Malawi, Sierra Leone and Sri Lanka) lack such confirmation. There are laboratory confirmed *M. ulcerans* infections in the following **tropical** regions and countries: 1) Africa: Angola, Benin, Burkina Faso, Cameroon, Ivory Coast, Democratic Republic of Congo, Equatorial Guinea, Gabon, Guinea, Liberia, Nigeria, Republic of Congo, Sudan and Togo; 2) The Americas: French Guiana, Mexico, Peru, and Suriname; 3) Asia: Malaysia, and 4) Oceania: Papua New Guinea and Australia. The **non-tropical** countries with confirmed BU are Australia, China and Japan. The use of microbiological tools has identified new foci in many of the endemic countries — for example, Burkina Faso, China, Equatorial Guinea, Guinea, Togo and Sudan.

Laboratory confirmation is essential in establishing prevalence and incidence of BU in new foci of the disease. Both the overestimation and underestimation of the BU burden of disease must be avoided to minimize mismanagement at the patient level, and inappropriate allocation of resources at the regional and national level.

SAMENVATTING. — *Buruli Ulcus: een historisch overzicht bijgewerkt tot 2005.* — Dit artikel brengt een overzicht van de geschiedenis van Buruli ulcer met speciale aandacht voor de ontdekkers van de eerste gevallen en de waarnemingen te velde in Kongo door P. G. Janssens. De tekst werd oorspronkelijk opgesteld door P. G. Janssens en werd bijgewerkt door drie van de mede-auteurs tot en met 2005. De eerste BU-haarden werden ontdekt in 1937 in Australië, in 1942 in Tropisch Afrika en in de jaren 1950 in Nieuw Guinea.

Onderzoek in Afrika gebeurde tijdens de moeilijke overgangsperiode van het koloniale regime naar de nationale gezondheidsdiensten. Vele medici hadden een belangrijke ervaring met tropische phagedemische ulcera waardoor hun interesse voor BU gewekt werd. *M. ulcerans* wordt thans geïdentificeerd op basis van fenotypische en genotypische microbiologische testen. BU werd beschreven in 30 landen maar slechts in 25 landen gaat het om microbiologisch bevestigde gevallen. Gevallen uit Malawi, Sierra Leone, Sri Lanka, Kiribati en Indonesië werden niet bevestigd.

Haarden met bevestigde gevallen zijn vooral gelegen in tropische gebieden van 1) Afrika (Angola, Benin, Burkina Faso, Kameroen, Ivoorkust, Gabon, Guinea, Equatoriaal-Guinea, Liberia, Nigeria, Democratische Republiek Congo, Uganda, Soedan, Togo); 2) Amerika (Frans Guyana, Mexico, Peru, Suriname); 3) Azië (Maleisië) en 4) Oceanië (Papoea-Nieuw Guinea en Australië). Bevestigde BU-gevallen werden ook waargenomen in niet-tropische streken van Australië, China en Japan.

Door het gebruik van nieuwe technieken worden regelmatig nieuwe haarden ontdekt (Burkina Faso, Guinea, Equatoriaal Guinea, Togo, Soedan, China).

Laboratoriumbevestiging blijft noodzakelijk om de juiste prevalentie en incidentie van de aandoening te bepalen en nieuwe haarden te documenteren. Overschatting van het aantal BU-gevallen dient vermeden om onaangepaste behandelingen te voorkomen.

RESUME. — *Ulcère de Buruli: un panorama historique actualisé jusqu'en 2005.* — L'objectif principal de ce panorama est de décrire l'historique de la découverte de l'Ulcère de Buruli (UB), de rendre hommage aux pionniers scientifiques et aux patients concernés et de relater également l'expérience médicale et de terrain de P. G. Janssens dans la découverte des premiers cas d'UB au Congo. Le texte, écrit initialement par P. G. Janssens, a été actualisé jusqu'en 2005 par les trois autres co-auteurs. Les premiers foyers d'UB ont été découverts en Australie in 1937, en Afrique tropicale en 1942 et en Nouvelle-Guinée dans les années 1950.

Les recherches cliniques et en laboratoire sur l'UB et son agent étiologique, *Mycobacterium ulcerans*, ont été menées en Afrique pendant la période ardue de transition entre le système colonial et les services de santé nationaux. En Afrique, les médecins avaient une grande expérience du diagnostic et du traitement des ulcères tropicaux phagédéniques. Ils ont, de ce fait, été les premiers à décrire les infections à *M. ulcerans* qui, quoique présentant des similarités avec les ulcères phagédéniques, constituaient une maladie à part. Les scientifiques australiens disposaient déjà à cette époque de laboratoires sophistiqués et de patients atteints d'UB. Ils ont donc contribué, de manière significative, aux premières descriptions de la maladie et à la culture de l'agent étiologique.

Pendant les 10-15 années passées, les connaissances sur l'épidémiologie et la pathogenèse de l'UB se sont largement étendues. *M. ulcerans* est actuellement identifié par des tests microbiologiques phénotypiques et génétiques.

Sur les 30 pays qui ont recensé des cas d'UB, 25 ont des cas confirmés par la microbiologie. Les cas du Malawi, de Sierra Leone, du Sri Lanka, Kiribati et d'Indonésie n'ont

pas été confirmés. Les foyers avec cas confirmés sont principalement situés dans les régions **intertropicales**: 1) l'Afrique: Angola, Bénin, Burkina Faso, Cameroun, Congo-Brazzaville, Côte-d'Ivoire, Gabon, Ghana, Guinée, Guinée-Equatoriale, Liberia, Nigeria, République Démocratique du Congo, Ouganda, Soudan, Togo; 2) les Amériques: Guyane française, Mexique, Pérou, Suriname; 3) l'Asie: Malaisie; 4) l'Océanie: Australie, Papouasie Nouvelle-Guinée. Des cas ont également été confirmés en zones **non tropicales**: au sud de l'Australie, en Chine et au Japon. Les tests microbiologiques ont permis de découvrir récemment des nouveaux foyers d'UB, par exemple au Burkina Faso, en Chine, en Guinée, en Guinée-Equatoriale, au Togo et au Soudan.

La confirmation microbiologique des cas est importante pour connaître la réelle prévalence et incidence de l'UB dans les régions endémiques et pour attester l'existence de nouveaux foyers. Elle est essentielle pour éviter la surestimation ou la sous-estimation du nombre de cas, le traitement inadéquat de patients atteints d'autres maladies et l'utilisation inappropriée des ressources au niveau régional et national.

1. Introduction

Buruli Ulcer (BU), caused by *Mycobacterium ulcerans*, is an indolent necrotizing disease of the skin, subcutaneous tissue and bone. BU is presently the third most common mycobacterial disease of humans, after tuberculosis and leprosy, and the least understood of the three. Cutaneous ulcers caused by *M. ulcerans* were discovered at nearly the same time in 2 antipodal regions: in 1937 in south-east Australia and in 1942 in tropical Africa. At the time, these discoveries did not excite much interest in the medical/scientific world. However, anyone interested in how a medical curiosity is transformed into a topic of worldwide interest should study the initial report of MacCallum *et al.* (1948) on their observations and pioneer findings in *M. ulcerans* infections. The disease was named "Buruli ulcer" after the geographic area of the first large epidemic investigated in Uganda (in 1961), in a county named "Buruli" (now called "Nakasongola"), near Lake Kyoga (Clancey *et al.* 1961, Dodge & Lunn 1962).

In spite of the increased interest in BU, the disease remained largely ignored by many national public health programmes for decades (Aujoulat *et al.* 1996). In 1998, the World Health Organization recognized BU as an emerging health problem, primarily because of its frequent disabling and stigmatizing complications (World Health Organization 2000).

BU is endemic in Africa, particularly in West African countries. The disease is also endemic outside Africa, but remains uncommon in non-African countries.

This article is an overview of the history of the disease, with the main objective of emphasizing the discovery of BU and the pioneer scientists involved. Historical data were completed by more recent data from countries where this disease was recently rediscovered or described for the first time, and where most cases were confirmed by microbiological tests (World Health Organization 2001) carried out at the Institute of Tropical Medicine (ITM), Antwerp, and the Armed Forces Institute of Pathology (AFIP), Washington DC.

2. Early Findings in Foci in Australia, Papua New Guinea, and Tropical Africa

2.1. Australia

The etiologic agent was discovered in Bairnsdale, Victoria State, in a temperate zone of southeastern Australia. This area is a farming district near the mouth of the Mitchell River where it enters Gippsland Lake. Searle, Clay, and Alsop, general practitioners in the Bairnsdale area, and Torode in Colac recognized indolent ulcers with undermined edges in the late 1930s. Biopsy specimens of these ulcers contained acid-fast bacilli (AFB). Unfortunately, these perceptive observations were never published.

The first patient reported by MacCallum *et al.* (1948) was a 2-1/2-year-old boy hospitalized on 29 June 1940 in a private clinic in Bairnsdale, with an ulcer on his leg. A biopsy from the margin of the ulcer teemed with AFB. The child died from an acute abdominal condition, but a necropsy did not reveal the cause of death. The second patient, 1 of 4 with similar skin ulcers hospitalized in the same private clinic, was a 16-year-old female admitted while the first patient was still under treatment. Her ulcer developed following an abrasion over the right shin caused by a fall on the stairs, and the clinician noted the similarity of this lesion to that of the first case. She was discharged healed after 18 months.

The third patient, a 51-year-old farmwife, was admitted with a history of a pinhead-sized sore on the lower third of the left shin that, after 5 to 6 months of local treatment, had become an ulcer about one inch in diameter with a deep, sloughing base and raised, indurated edges. Sections of biopsies showed abundant AFB, staphylococci, and diphtheroids. In April 1941 she was transferred to the Alfred Hospital in Melbourne for further investigation. After 15 months she was returned to the local clinic and the lesion healed after 17 months. The fourth patient, a 13-year-old boy, was admitted 3 years later to the same clinic following an insect bite, but was transferred to the Alfred Hospital in March 1944. The lesion began locally as a small, nontender lump on the upper part of the left shin. The nodule broke down, leaving a deep excavation. Excision of the edges was followed by extension of the ulcer. After local treatment, bouts of fever, and persistence of numerous AFB, he elected to return to the clinic, where he remained for 7 months. It took 15 to 16 months for the ulcer to heal.

The fifth patient, a 45-year-old woman, presented 6 years after the first patient. She had noticed a subcutaneous induration ("like a bull ant bite") on her inner left forearm above the wrist, which gradually enlarged to one inch in diameter before breaking down in the centre. The appearance was "like an ulcerated epithelioma", but there were abundant AFB in smears. Culture attempts on Dorset's egg medium were negative. The sixth patient, a male dairy farmer 20 years of age, was from Colac, a dairy district over 200 miles from the Bairnsdale cluster. He became the first patient from whom the etiologic agent was cultured. The painless ulcer was near the middle of the lateral surface of the left forearm. The lesion began as a small pimple which developed a purplish centre that sloughed, leaving an ulcer surrounded by inflamed edematous skin. The adherent "chamois leather-like" area doubled in diameter over one week. Treatment with sulphadiazine and penicillin led to initial improvement, but the ulcer extended. Excisions and skin grafting were successful. On examination in April 1947, 4 of the Bairnsdale patients were in good health.

A team from the Pathology Departments of Melbourne University and Alfred Hospital, under the leadership of MacCallum, dramatically described all the salient features of what we now know as "Buruli ulcer". The typical feature was an indolent ulcer with undermined edges in an otherwise healthy individual. The disease originated in indurated skin as a small lesion which extended inconspicuously in the subcutaneous tissues. Sloughing led to denudation of a large area which continued to extend at the edges. In the necrotic base there was an abundance of gelatinous material containing many AFB. The constant presence of AFB convinced these investigators that they were the etiologic agent, and not contaminants.

A bacteriological study of the AFB by MacCallum *et al.* (1948) included attempts to cultivate the organism from lesions on mycobacterial media available at the time (Löwenstein-Jensen, etc.). All such attempts on the first 5 patients failed. Inoculation of laboratory animals by the usual routes provided interesting information. For example, guinea-pigs could not be infected. Male white rats inoculated intraperitoneally developed distended abdomens after 9 months, and at postmortem 50 ml of ascitic fluid loaded with AFB was recovered. All attempts to cultivate the AFB *in vitro* failed. One rat, forgotten after inoculation at 16 months, showed surprising changes: swollen, edematous, ulcerated limbs, a sloughed-off tail, and ulcerations swarming with AFB. From these observations the investigators deduced that the AFB were the cause of ulceration in humans. This strain and one from the fourth patient were maintained in rats for years. In 1974, Fenner published a historical perspective of the "Bairnsdale bacillus", or *Mycobacterium ulcerans* (Fenner 1974).

Buckle and Tolhurst in the MacCallum *et al.* publication present a clear and vivid account of the long, frustrating road that led to the *in vitro* cultivation of this new mycobacterium (MacCallum *et al.* 1948). Employing currently available media for the culture of tubercle bacilli, and using inocula from patients 3 and 4 and peritoneal fluid of rats infected from these patients, all attempts at cultivation failed. They attributed failure to a lack of some growth factor. Based on this premise, they added vitamins, suspensions of killed mycobacteria, sterile human tissue, and sterilized tissue from the ulcer of patient 4, without success.

Inoculation in the yolk sac of chicken embryos likewise failed. Thus, investigation of the thesis for the "absence of a growth factor" was not fruitful. All sorts of variations in cultivation atmosphere, such as anaerobiosis and changes in carbon dioxide concentrations, failed at 37 °C or room temperature. In the course of their overwhelming series of failures, poor and irregular cultures were sometimes observed with inocula from infected rats, but subcultures were uncertain.

In the midst of this perplexity, 2 serendipitous observations led to success: 1) lesions in infected male rats appeared only on limbs, tail, or scrotum — body regions with temperatures lower than 37 °C; 2) the poor but definite cultures had been incubated in a defective incubator with variable temperatures in different internal loci. After adjusting the incubator to 32 °C, the approximate temperature of loci favourable for growth of the organism, cultures from stored infected fluids were regularly successful. As a crowning achievement, cultures were obtained using inocula taken directly from patient 6. The necessary conditions for cultivation had finally been established.

Isolating *M. ulcerans*, even at 32 °C, remains difficult under some logistical conditions. But from this point on, the way was open for observing cultural characteristics and perfecting techniques for *in vitro* cultivation. The causal relationship of this AFB to typical ulcers was now established. Although these authors did not propose a name for the organism, *M. ulcerans* was "born" and its identification as the etiologic agent of a distinctive disease was established. The Australian bacteriologist Woodruff drew attention to the unique histopathological features of the lesion in patients: abundance of AFB in clusters, absence of neutrophilic infiltrates, and bland necrosis without a granulomatous reaction. Along with edema and mild inflammatory infiltration by exudates, the periphery and base of lesions were necrotic. The necrosis extended into the fatty tissues and, surprisingly, far beyond the ulcerated area. The affected areas regularly contained large numbers of AFB, mostly in sharply defined masses, with no other etiologic agents present. The absence of typical granulomas and nerve involvement was significant.

MacCallum *et al.* recognized their indebtedness to the Bairnsdale physicians for identifying the specific skin ulcers and for compiling clinical data, and to Woodruff for the initial observations, as well as to the research team at Alfred Hospital for growing the etiologic agent. The discovery of the third most common mycobacterial pathogen of humans will undoubtedly be an enduring landmark in the annals of Australian medicine, and is today the stimulus for the development of a regional Reference Laboratory at Fairfield Hospital, Melbourne, Victoria.

The most prominent topographic feature of the endemic regions was the proximity of rivers, swamps, lakes, and areas subject to flooding, and although natural reservoirs were considered likely, none was found. Animals with low body temperatures (fish, amphibia, herpetofauna, rodents, even bats) were considered as possible reservoirs. Insects were closely investigated but never proven to be reservoirs. As portals of entry, trauma and dissemination by aerosols were incriminated, but without proof. Australian practitioners and scientists remain attentive to this problem. The first infection in a wild koala was discovered on Raymond Island (MITCHELL *et al.* 1984). In recent years a microepidemic of *M. ulcerans* disease on Phillip Island, Victoria has provided data on the epidemiology of Buruli ulcer (FLOOD *et al.* 1994; HAYMAN 1987; JOHNSON *et al.* 1995, 1996).

Around Bairnsdale the disease is still sporadic, but the main focus in Australia is around Cairns, in northern Queensland. Buckle localized the early foci as follows (BUCKLE 1972): Northern Territory (Croker Island) (QUINN & CROTTY 1963), 4 cases; northern Queensland along the eastern coast around Cairns, 25 cases; Victoria (Yaltourn and Hamilton), 21 cases; New South Wales, Brisbane, 1 case.

Between 20-30 microbiologically confirmed cases are now reported annually in Australia where the disease is usually diagnosed at early stages. Thus in Australia the disease remains uncommon (JOHNSON *et al.* 2005, World Health Organization 2004).

2.2. PAPUA NEW GUINEA

Although probably recognized in the 1950s, Reid saw the first *M. ulcerans* patients in New Guinea in 1962 and reported them in 1967: 2 patients in the Western District and 11 in the Northern District (REID 1967). One focus in the Northern District was in the village of Siai along the Kumusi River. There were a few sporadic cases elsewhere in the same district. These infections appeared after a flood and were known locally as “Kumusi ulcer”. The total number of infections increased to 190 in 1974 when Radford recorded 112 cases in 4 districts and an additional 65 from other areas (RADFORD 1974, pp. 129-144, 145-149). Next to the Siai cluster, Wewak, in the East Sepik District, had the highest prevalence: 67 cases diagnosed in a 3-year period. Eleven cases were also found in West Sepik and the Madang District. In 1988 Igo and Murthy studied 46 biopsy specimens taken in East Sepik and all had typical histopathologic lesions (IGO & MURTHY 1988). In 1974, Lytton and Lavett examined biopsy material from Port Moresby, taken from 1972 to 1973, and drew attention to dystrophic calcifications in necrotic fat and collagen (LYTTON & LAVETT 1974). Dawson, in 1974, described the bacteriology of lesions of *M. ulcerans* infection in New Guinea (DAWSON 1974). From 1971 to 2003, 433 cases were reported (World Health Organization 2004). The disease, however, remains uncommon, with less than 50 new cases each year (Sister Joseph, personal communication). Most of these recent cases have been confirmed by bacteriological tests at the ITM.

2.3. TROPICAL AFRICA

Current observations on the distribution of *M. ulcerans* infections in tropical Africa reveal this area as the major focus of the disease in the world: at least 16 countries are endemic.

In this historical survey, special attention is paid to the fact that research on *M. ulcerans* took place in Africa during an arduous transition period from colonial to national health services. Efforts to assure optimal public health care delivery were often hindered by inadequate numbers of trained personnel; nevertheless, important programmes were maintained. Of special importance was the control and treatment of some endemo-epidemic diseases such as leprosy, yaws, and venereal diseases. Of particular relevance to *M. ulcerans* infection was the long history of experience, both personal and general, of treating tropical phagedenic ulcers (TPU). A brief account of this history reveals the importance of programmes for TPU in stimulating initial interest in other cutaneous ulcerative diseases in the tropics.

TPU was a particular problem in economically important activities such as mining and the operation of plantations. In 1921 Van Nitsen reported that in 6 months he saw 142 patients with TPU in the Lubumbashi Hospital, and that the average hospital stay was 32 days (Van Nitsen 1921). During the period of 1939 to 1941 at Mongbwalu Hospital (Kilo-Moto Goldmines), among 10,650 men, 6,115 women, and 4,431 children hospitalized, 59.9 %, 41 %, and 30.4 %, respectively, had TPU.

3. Some Personal Experiences reported by P. G. Janssens

In 1942, Lubicz, my colleague at Tora Hospital, about 400 km north of the Kilo Medical Laboratory in Congo, mailed me some smears on slides. The smears were from a necrotic ulcer on the leg of a miner at the Kakerifu alluvial gold mine. This ulcer did not respond to treatment for TPU. The smear contained AFB, even though the patient had neither leprosy nor tuberculosis. My colleague wanted to know if it was possible to classify this AFB morphologically. That was not possible, but I was eager to culture the bacterium and put it into animals. Thus began a long and fascinating adventure. Culture was unsuccessful, but the mycobacterium grew in rats, while guinea-pigs were resistant.

Being deeply involved with the TPU problem, the Kilo-Moto medical service could show only a limited concern over a few isolated chronic necrotizing ulcers containing AFB and affecting mostly children in the Kakerifu encampment situated between the Kibali and Nzoro rivers. Nevertheless, these cases profoundly stimulated my scientific curiosity. At that time, primitive logistics hindered all aspects of scientific inquiry, including the identification of microbes. In addition, the newly discovered necrotizing ulcers aroused only marginal interest among the medical authorities. Furthermore, the science of mycobacteriology in the early 1940s was not well developed. A variety of mycobacteria were known but little understood: *M. tuberculosis, M. bovis, M. avium, M. lepraemurium, M. leprae, M. fortuitum, M. scrofulaceum*, and miscellaneous saprophytic mycobacteria. The first attempt to classify these organisms by cultural characteristics came some 13 years later (Timpe & Runyon 1954). In this context it was not surprising that, using classical methods of the time, I did not succeed in cultivating *M. ulcerans* at 37 °C or ambient temperature (about 25 °C), or even in anaerobic or elevated CO_2 conditions on Löwenstein-Jensen, after decontaminating with 3 % hydroxide. Further studies showed that guinea-pigs were not susceptible but rats could be infected by different injection routes, especially intratesticular, but the mycobacteria harvested from animals could not be cultivated *in vitro*.

As it happened, I subscribed to the *Journal of Pathology and Bacteriology* (London), when my *Zentralblatt fur Bakteriologie, Parasitenkunde, Infektionskrankheiten und Hygiene* was no longer available after 1940. Thus, I was surprised and most satisfied in 1948 to see the now famous publication by MacCallum, Tolhurst, Buckle and Sissons, and to learn of the existence on the other side of the world of a similar necrotic ulcer caused by an AFB in a small focus in southeastern Australia. This was an encouraging event for a lone bacteriologist in the northeast corner of the Belgian Congo (later Zaire, then Democratic Republic of Congo or DRC). The lesion was then called "Bairnsdale ulcer" (other names based on endemic foci would include Kakerifu, Tora, Kasongo, and finally Buruli ulcer) and the AFB *M. ulcerans*. The histopathologic changes were similar and the mycobacterium grew only at 32 °C. I could now start anew and did so immediately.

The transportation of suitable clinical material was well organized by Van Yzendijk, a dynamic young doctor in charge of the Tora Hospital. After much discussion it was agreed that a boy with a closed lesion should make the 400-km trip by road from Tora to Kilo. He arrived unannounced at Kilo Hospital and the doctor in charge tried patiently, in spite of a language barrier, to learn what the problem was. When he understood that a lesion on the boy's leg should be excised, he proceeded forthwith to do so. After closing the lesion and dressing it, he sent the boy back to Tora immediately. In the early afternoon, I received a letter from Tora by mail informing me that the child was coming to Kilo. Rushing to the hospital, I got the unfortunate news that the biopsy had already been thrown away. It was then agreed that the next attempt should be better planned, but there was never a second attempt. Instead, in 1949, I spent 4 to 5 months at Tora Hospital. My first priority was to visit the Kakerifu alluvial mining yards, to gather firsthand knowledge of the general ecological setting of *M. ulcerans* infections. This knowledge would become extremely useful in 1957 when I went to the Kasongo region of the Maniema in eastern Congo.

A few days after my arrival at Tora, Dolomo, the capable leader, showed me a girl with an extensive edematous lesion of the arm and elbow and told me "this is a necrotic ulcer". To my surprise, he stated he had punctured the lesion, made a smear of the exudate and stained it by the Ziehl-Neelsen method, and observed AFB. I confirmed his observation readily, but I asked why he had never informed the former doctors about this peculiar lesion. The answer was no surprise: he stated that as a rule he called the attention of each newly arrived physician to some of the lingering disease problems and waited to see if he showed any interest. If he did not, the problem was shelved and business carried on as usual.

During my 13 years of practice I had become aware of the fact that a fair number of our auxiliaries (trained nurses assistants), and some of the many others I met later in many East or West African countries, including a Minister of Public Health, were to some extent associated with traditional practitioners. This fact had convinced me that the original sin of the colonial medical service was its aim to eradicate traditional medicine as being both useless and a hindrance to Western medicine. Dolomo was not only related to traditional practitioners, but was himself an active traditional practitioner. However, he limited his practice to diseases against which Western medicine did not have effective treatment. Psychiatrists became the first to realize that a close collaboration with traditional healers was more fruitful than constant disregard or even hostility. I came to believe that an invaluable, though often neglected, source of medical information is the appellation in a local language given to a mysterious morbid condition.

On January 1, 1950, I took charge of the Leopold II Clinic of the ITM at Antwerp and brought along a strain of the Kakerifu *M. ulcerans* in a rat, but the strain was lost. At the February meeting of the Belgian Society of Tropical Medicine, the report by Van Oye & Ballion (1950) of a case of *M. ulcerans* on the left foot of a 6-1/2-year-old boy of an American missionary family living in the Bandundu Province was an exciting surprise (Meleney & Johnson 1950, Meyers 1975). At this meeting I related that I was aware of more than 80 such necrotic lesions in a focus around Kakerifu. The description fit that of the Bairnsdale ulcer and the lesion contained AFB. I also noted that there was clustering of the cases in savanna terrain, and that the water used in alluvial gold mining came from this area. I had not published these observations because I was not able to cultivate the etiologic agent.

The American boy was transferred to the Presbyterian Hospital in New York and managed by Meleney and Johnson (Meleney & Jonhson 1950). Secondary infections by streptococci and staphylococci were effectively treated with antibiotics, but the AFB persisted and the undermined ulcer did not improve. Dubos and Middlebrook at the Rockefeller Institute tried unsuccessfully to isolate the mycobacterium. Local heat therapy was ineffective and the lesion was surgically excised. The boy left the hospital healed after 4-1/2 months. Meyers *et al.* made a thorough investigation of the residence and travel history of this patient in the Congo, because Bandundu was not yet known to be a focus of Buruli ulcer (Meyers 1975). The boy had visited the Bas-Congo, but had never resided there. By 1974 he had had several revisions of the foot, but had no crippling deformity.

From 1950 to 1953, Sieniawski was in charge of Tora Hospital. From his studies of the Kakerifu focus, he confirmed the classification of the edematous form on the lower eyelid of a 4-year-old child, with no involvement of the eye. As a general therapeutic approach, he emphasized the need to avoid unusually extensive excision and the importance of physiotherapy to prevent crippling. Because of the risk of fatality in children with massive lesions, Sieniawski was more conservative in excising lesions. He also discovered foci at Wandote on the right bank of the Kibali River (Kakerifu is on the left bank) and at Giro near the Yebu River. In 1962 Van den Abbeele at Bunia isolated a strain of *M. ulcerans* from a patient at Tora and sent it to the ITMA for study (Van den Abbeele 1962).

3.1. The Kasongo Focus

When I first visited Kasongo in 1957, I was impressed by the savanna terrain dotted with brooks and fishponds (tilapia pisciculture), and its similarity to Kakerifu with its alluvial mining operations. During my next visit to Kasongo in 1958, Quertinmont, surgeon and hospital manager, showed me necrotic ulcers with AFB. He studied in depth many aspects of *M. ulcerans* infections, with the assistance of Pattyn and Gatti. From these observations he wrote an impressive thesis which was published in 1959 (Janssens *et al.* 1959). His findings were consistent with then current concepts of BU. Clinically he observed preulcerative solitary nodules that were barely palpable, movable, but not painful. These nodules would ulcerate and discharge seropurulent fluid. The borders were undermined and extended slowly, and the surrounding skin was hyperpigmented. In the centre there was necrotic tissue, and the necrosis spread deeply into the subcutaneous tissue. Satellite lesions sometimes appeared at some distance from the original ulceration. One patient had extensive edema of the limbs and thorax. Exudates from such lesions were sometimes rich in AFB. Eventually, extensive and rapidly progressing ulceration ensued, accompanied by damage to underlying tissues. Foci of calcification were noted in the subcutis.

Radiological investigation showed changes in bone, especially softening in long bones and in bones of the hands and feet, frequently accompanied by fractures of the cortex. Osteomyelitis often produced crippling deformities. There were no pulmonary lesions, and the patients' general health was good, except for those with the most extensive lesions. No clinical adenopathy or fever was noted. Histopathologically, the inflammatory reaction in the dermis was nonspecific, but the panniculus was necrotic. Vasculitis and thrombosis of blood vessels and calcification were mentioned. AFB were abundant, but there were no granulomas.

Epidemiologically, the disease was localized in clusters in a swampy savanna, away from the Maniema forest. In 1957 there were 23 patients: 16 were 5 to 15 years old, 3 were adolescents, and 4 were adults. Suggested sites of entry of *M. ulcerans* were abrasions or punctures by thorns, sharp grasses or splinters, or injuries from leeches acquired while wading in water.

Culture was successful from one closed lesion and 4 ulcers. The colonies were rough, white to cream yellow, and ultimately orange. Rats were susceptible on testicular inoculation and guinea-pigs were resistant. Intradermal skin tests were as follows: tuberculin (Mantoux), negative or occasionally weakly positive;

lepromin (Mitsuda), positive in 10/12; *M. avium,* strongly positive; extracts of *M. ulcerans* cultures (Kasongo strain), weakly positive at 15 days.

Broad excision was the only effective therapy. The mycobacteria were not sensitive to sulfanilamide or antibiotics. Thermotherapy at 45 °C was ineffective.

3.2. Other Foci in the Democratic Republic of Congo

In 1960, Pattyn made a histopathologic diagnosis of an *M. ulcerans* infection in a boy 7 years old who was hospitalized in southeastern Congo at Lubumbashi in Shaba. In a review of 5,000 other archival biopsy specimens collected at Elisabethville (Lubumbashi) Laboratory between 1949 to 1960, Pattyn found no other lesion consistent with Buruli ulcer (Pattyn 1961).

In 1962, Hennebert *et al.* at Kinshasa described 2 patients with BU: a 28-year-old woman from Bandundu near the confluence of the Kwilu and Kasai rivers, and a 6-year-old boy said to be from Kinshasa (Hennebert *et al.* 1962). One other patient, an Italian nun who had lived for years in Kinshasa, was treated at the ITM for Buruli ulcer in 1974 (De Bergeyck *et al.* 1980).

In 1974, Meyers *et al.* published an exhaustive account of *M. ulcerans* infections in Congo and concluded that there were 6 foci in its 8 regions (Meyers *et al.* 1974). Meyers deduced from personal communications that the disease had prevailed in Congo for many years. Kleinschmidt, the respected physician based first at Ibambi and later at Aba (on the Sudan border), during his itinerant medical service in the northeast (1923 to 1964) saw numerous ulcers containing AFB in patients without leprosy in the Watsa-Moto area. They were not evaluated further but were probably *M. ulcerans* infections. Detailed interviews in the Bas-Congo also strongly supported the concept that BU was an ancient disease in that region. In the Equateur region, 2 patients from Lukolela near Mbandaka on the Congo River were identified. In Bandundu, the Baptist Hospital at Bolobo treated 13 patients with Buruli ulcer. All patients from Lukolela and Bandundu were confirmed histopathologically.

Meyers *et al.*'s main contribution concerned the Bas-Congo. Andersen (1965) and Smith (1970) respectively, reported 28 cases (1961 to 1964) at the Institut Médical Evangélique (IME) at Kimpese, and 97 patients treated at Kimpese or the Baptist Mission Hospital at Nsona Mpangu, both in the Songololo territory. For the period 1960 to 1973 the number of patients was 180. The Bas-Congo focus extended south into Angola and north across the Manianga into Congo-Brazzaville. The authors recounted the following incident: during an impromptu visit to the village of Mpangu (150 inhabitants) near Songololo, the chief drew their attention to the fact that besides the 4 patients who had been treated at Kimpese, there were 13 additional patients, 3 with severe deformities. Three others had died of extensive lesions.

More than 500 BU cases had been reported in the Democratic Republic of Congo before 1980.

After 1980, there was a "silent" period with no reported cases during 20 years partly due to the political situation in the country.

From 2000 until present, new cases have been reported in all foci described by MEYERS *et al.* (1974), confirming that the disease is still active in the country. A nationwide survey conducted in 2004 identified 487 cases. Microbiologically confirmed cases were found in the following Provinces: Bas-Congo, Bandundu, Kinshasa, Maniema, Katanga and South-Kivu (KIBADI *et al.* 2006).

An apparent resurgence of BU was reported in the Bas-Congo Province between 2002-2004. During this period 51 patients were admitted at the IME at Kimpese and 36 cases were confirmed (PHANZU *et al.* accepted).

4. Other Foci in Africa

4.1. EAST AFRICA

4.1.1. Uganda

The sudden appearance of 220 patients with BU among Watutsi refugees from Rwanda living near the Nile River in Uganda led to a systematic survey in 1965. However, Clancey *et al.* had already drawn attention to the hospitalization of patients with necrotic skin ulcers containing AFB at Mulago Hospital, Kampala, beginning in 1958 (CLANCEY *et al.* 1961). The lesions were similar to the Bairnsdale ulcer and those identified in Congo by Van Oye and Ballion (VAN OYE & BALLION 1950). Of the 40 Kampala patients, 28 came from the Buruli area in the Mengo District on the southern bank of the Victoria Nile and Lake Kyoga. This area was mainly a sparsely populated scrubland 60 to 80 miles north of Kampala.

Dodge and Lunn described a typical patient, a 13-year-old Muganda girl who had scratched her left forearm on a thorny bush. After 3 weeks the superficial wound became painful and swollen, and broke down with suppuration. On admission there were 3 separate lesions: a shallow ulcer at the elbow, a large subcutaneous mass on the forearm, and a lump on the wrist. By that time the etiology had been established: *M. ulcerans* had been cultivated at 33 °C, animals had been inoculated, histopathologic changes defined, and the lesions excised and grafted. Because of the origin of many of their patients, Dodge and Lunn named the disease "Buruli ulcer" (DODGE & LUNN 1962). In 1966 Connor and Lunn published a perceptive study on the pathology and pathogenesis of 38 patients from this area (CONNOR & LUNN 1966). These observations led to the discovery of the cytotoxin elaborated by *M. ulcerans* and which plays a major role in the pathogenesis of Buruli ulcer (HOCKMEYER *et al.* 1978, READ *et al.* 1974).

In 1965 Lunn *et al.* noted that 1 of the 40 patients which were being studied by Clancey *et al.* was from the Madi District in the extreme northwest corner of

Uganda near the Nile River at the Sudan border (LUNN *et al.* 1965). Guwatudde, the District Medical Officer of that area, had reported to officials in Entebbe in 1962 that there were many patients in his hospital with skin ulcers. Lunn and Connor visited this district in May 1963 and confirmed the existence of this endemic focus of BU. In September 1963 a special medical team was formed and went to the area. In 3-1/2 months, 48 cases were identified. In the local language the lesions were called *juwe okoro* or *bibi okoro*, indicating the inhabitants' familiarity with this disease, which they treated by traditional methods (powdered local herbs). An association between BU and the Nile River was noted. The team found no convincing evidence for a source of the etiologic agent, such as grasses, fish, insect vectors, or nonhuman reservoirs.

4.1.1.1. The Kinyara Focus and all Uganda

In 1964, some 2,500 Rwandan Watutsi refugees who had fled Rwanda after 1959 and were living in different regions of Uganda were settled by the United Nations High Commission for Refugees in a camp at Kinyara, in the Bunyoro District 2 miles from the Nile. In February 1965 the first BU patient was seen, to be followed by 14 additional cases. Revill, Medical Officer in charge of Masindi General Hospital, held regular monthly clinics for BU beginning in January 1966. At the first session 31 new patients showed up. The monthly increase of cases averaged 6.5 and the incubation time was estimated at around 2 months.

The Uganda Ministry of Health and the Makerere Medical School, in the meantime, had instituted the Uganda Buruli Group, with a mandate to investigate the BU problem and to advise the authorities on strategies for managing this significant public health problem. Their first report in 1969 described the clinical aspects of the disease (Uganda Buruli Group 1969). Their second report again emphasized the clinical features and the importance of early treatment, preferably in the preulcerative stage (Uganda Buruli Group 1970). Taking into account that the Kinyara community was a relatively isolated area into which a relatively homogeneous group of people was introduced into an active focus of BU, this was an excellent opportunity to make original observations on the initial stages of the disease. In fact, all of the practitioners involved in the treatment of BU were aware of the advantages of excision of the early localized nodule, limited to the area containing necrotic subcutaneous fat and numerous AFB. Such excisions would assure healing by primary intention. Likewise, they were aware of the more complex and time-consuming surgical management and skin grafting of the fulminating extensive lesions, often resulting in significant disability. The third report of the Uganda Buruli Group produced important details on the epidemiology of BU (Uganda Buruli Group 1971). It is important to note that the Kinyara refugee setting was an artificial development that was abandoned in 1968. At Kinyara the Watutsi lived in an agrarian community close to the Nile, but not in direct contact with the river. Although follow-up programmes were outlined, they were not implemented because of the transfer of the group to

Kanyangwali near Lake Albert, where they merged with refugees from other sites. After this relocation, BU developed in only 24 patients, with no further transmission. In Kinyara a total of 220 cases were recorded, mostly in children.

The Uganda Buruli Group set up for the Kinyara focus was a salutary effort because it called for attracted the attention of the medical profession and the general population to this serious health problem and underlined the importance of early detection. However, there was a general perception that this unique experience should be broadened to all of Uganda. This challenge was accepted by Barker of the Department of Preventive Medicine at Makerere University. In 1971, with the collaboration of the Uganda Buruli Group, he selected the Busoga District (90,000 inhabitants) as a trial site because BU had not been observed there before 1965, except for 2 patients from remote parts of the district. By 1967 to 1968, the number of infections had mounted to 13 and increased sharply to 55 from 1969 to 1970. A similar increase had been observed by Revill in 1970 in the districts of Lango, Bunyoro, East Menge, and Madi. Of all the arguments brought forward on the cause of the increase, the most widely accepted one was the ecological changes produced by the floods of 1962 to 1964. A decline in cases began in 1972 (REVILL *et al.* 1973).

In 1971, Barker began a comprehensive survey of BU in the Busoga District on the east side of the Victoria Nile where it flows into the southern end of Lake Kyoga and including its Kilo tributary. He collected his data from the detailed records of a missionary physician at Kamuli Mission Hospital (59 cases) and a consulting surgeon at the Main Hospital (23 cases since 1967). These data were confirmed by 27 selected home interviews. In addition, of 197 patients with TPU identified in 15 dispensaries, and a large number of leprosy patients, only one had BU (BARKER 1971, 1972, 1973, 1974; BARKER & NINKIBIGAYA 1972; BARKER *et al.* 1972).

In 1972, the Busoga plan was adapted for a countrywide survey. Hospital visits were made and records studied, with emphasis on data from Lango and Bunyoro hospitals, the main centres for the treatment of BU. A study of the biopsy archival material in the Pathology Department of Makerere Medical School was conducted, along with a survey in counties suspected of having unreported cases (Serere in Teso, Palissa in Bukedi). A variety of other sources of information was employed, including interviews with authorities and individuals. A secondary-school boy, familiar with the disease, surveyed east Buganda on a bicycle for a month without detecting a single case of infection not already recorded.

The final record for Uganda in 1970 was 572 cases spread over 52 counties. The highest established crude annual incidence was 18.1/1,000 population in Ibuje, Lango District.

The distribution of BU in the 6 districts of Uganda with proven cases was as follows: Bunyoro 142; East Buganda 10; West Nile 4; Madi 49; Lango 327; Busoga 39; 17 counties had only 1 patient. Many demographic details are presented in the report, demonstrating the thoroughness of the inquiry. Of primary interest, the data show that the frequency of infections correlated mainly with the frequency of visits to swampy wetlands for agricultural or recreational activities (BARKER 1973).

Data from Uganda show convincingly that this endemic area was related to wetlands within 30 miles of the Nile River. The only recorded exception to a relationship with the Nile was at Rwebisengo, at the southern end of Lake Albert, an enormous reservoir of Nile water beyond Murchison Falls. The plains at the southern and northern ends are regularly flooded, and seasonal variations of BU in these areas have been observed.

The Uganda Buruli Group perceived that BU was related more closely to vegetation along the Nile River than with the water of the river itself. Whether the banks of the river confined the flow or allowed the river to flood the surrounding terrain seemed an important factor. Although never confirmed, the Group tended to believe that *Echinocloa pyramidalis* grass was involved in the transmission of *M. ulcerans*. Many mycobacteria other than *M. ulcerans* were isolated from plants (BARKER *et al.* 1972); however, the inability to isolate *M. ulcerans* in this extensive study led the Group to abandon this avenue of research.

In 1976, the disease was believed to have disappeared (World Health Organization 2004). A few cases from the Nakasongola district (formely Buruli district) were however recently confirmed in 2004 by microbiological analyses (STRAGIER *et al.* 2006).

4.1.2. Sudan

Sudan was only recently recognized as a new focus of BU.

The first cases of BU were identified in 2001 in southern Sudan by Rudi Coninx from the International Committee of the Red Cross. These cases as well as more recent cases which were diagnosed by Yatta Lugor and Irineaus Sindani were bacteriologically confirmed at the ITM (STRAGIER *et al.* 2006).

4.1.3. Malawi

A few cases have been reported in this country since 2001. These cases were however never confirmed (World Health Organization 2004).

4.2. CENTRAL AFRICA

BU in Central Africa is not limited to the well-known foci in the DRC, but is also endemic in countries along the eastern coast of the Gulf of Guinea. Because of the high quality of its medical service and its continuing interest in necrotic cutaneous ulcers, the *Institut Médical Evangélique* at Kimpese has developed a close rapport with neighbouring regions on both banks of the Congo River far beyond the state boundaries. Thus, the Kimpese Group has been a valuable source of information about neighbouring countries, some of which are discussed briefly below.

4.2.1. Angola

A number of newly arrived Angolan refugees were treated for BU at Kimpese beginning in the early 1960s, indicating that Angola has long been endemic. Some recent evidence for BU in Angola was provided by an Angolan boy, aged 2-1/2 years and a resident of Caxito, Bengo Province (Bar *et al.* 1998). He was hospitalized at the Carl Thiem Klinikum at Cottbus, Germany, on 21 December 1992, suffering from severe kwashiorkor and a 20-×-25-cm ulcer with undermined edges on the left side of his thorax. This ulcer was clinically compatible with an active *M. ulcerans* infection, heavily superinfected with other bacteria. The ulcer was surgically excised and skin grafting was performed. Histopathologic findings were typical of BU and AFB were present. *M. ulcerans* was identified by PCR and culture.

A 4-year-old boy from Angola who presented with several ulcers and osteomyelitis, due to *M. ulcerans* and hospitalized in Ulm, was also reported (Pszolla *et al.* 2003). Recently, Phanzu *et al.* (accepted) reported that of 36 patients treated at the *Institut Médical Evangélique* at Kimpese, 15 (41.7 %) were Angolan.

Nothing is known about the frequency of BU in Angola, partly because of difficulties in this country. The high number of Angolan refugees treated for BU in Kimpese suggests that regions of Angola close to the DRC border may be endemic for BU. Surveys are urgently needed to determine the importance of BU in Angola.

4.2.2. Equatorial Guinea

According to personal communication with Meyers beginning in January 2000, during the period 1998 to 2000, Xuelu Zhou treated 9 patients in Equatorial Guinea at the *Hôpital Régional de Bata* with clinical and histopathologic features of BU. The patients came from coastal and interior areas of the country.

A multifocal, bacteriologically confirmed case of BU with associated osteomyelitis in an HIV-positive patient living in a rural area close to the border with Cameroon was recently published (Toll *et al.* 2005).

4.2.3. Gabon

In their 1968 overview of ulcers caused by mycobacteria, Carayon *et al.* presented the history of a mulatto boy, aged 14, hospitalized at the General Hospital of Libreville for edema and fistulas of the left knee (Carayon *et al.* 1968). The suspicion of tuberculosis could not be confirmed, but the histopathologic diagnosis was BU. The boy left the hospital 6 months later, following surgical excision, grafting, and physiotherapy. Burchard and Bierther reported an additional 23 patients from Gabon in 1985 (Burchard & Bierther 1985).

In 2005, 19 cases clinically diagnosed by Bayonne Manou were confirmed as BU by microbiological tests performed at the ITM. These findings thus indicate that the disease still exists in the country.

4.2.4. Republic of Congo (Brazzaville)

In 1966 Perquis and Muret published their observation of 8 patients with ulcerations due to mycobacteria and compatible with Buruli ulcer (PERQUIS & MURET 1965). The patients were living in Loutete, Madingou, and Dolisie in the Republic of Congo, in a region contiguous to Luozi in the DRC. A total of 390 cases have been reported between 2001 and 2003 but none of them was confirmed (World Health Organization 2004).

4.2.5. Central Africa: Conclusion

The large collection of foci in Central Africa, of which the reported cases are only the tip of a tropical "iceberg", should not be disregarded now that a formerly misunderstood medical curiosity has become a significant public health problem.

Surveys are urgently needed to determine the extent of BU in Central Africa.

4.3. WEST AFRICA

4.3.1. Benin

The first known observation of BU in Benin was made in 1977 in the *Hôpital St. Camille* at Dogbo (Mono Department), but the first publications, by Muelder, and Muelder and Nourou, concerned 28 patients in Ouinhi (MUELDER 1988, MUELDER & NOUROU 1990). This report aroused much interest in BU in Benin, and coincided with the onset of an epidemic that not only involved Benin, but virtually the whole of West Africa. From 1989 on, the *Centre Sanitaire et Nutritionnel Gbemoten* (GSNG) at Zagnanado (Zou Department) became the focal point for the management of BU patients. Data on 867 patients seen between 1989 and 1996 were published by Aguiar *et al.* (AGUIAR *et al.* 1997, AGUIAR & STEUNOU 1997, JOSSE *et al.* 1994). The carefully documented archival materials provided valuable information on symptoms and patient care. Only 3.5 % presented in the early preulcerative stage. The major foci were in southern Benin: Ouinhi, Zagnanado, Za-Kpota, and the river valleys of Ouémé, Zou, Mono, Couffo. With the ITM providing microbiological and molecular biologic studies, and the Armed Forces Institute of Pathology (Washington, DC) making histopathologic analyses, this effort has become a fruitful partnership, not only for the scientific advances realized, but for the direct salutary benefit to patient care. This comprehensive study has already given rise to the Benin Anti-Buruli Ulcer Program (PNLUB: *Programme National de Lutte contre l'UB*), which is becoming a model for other endemic African countries.

The first study on the largest number of patients (1,700) was published by DEBACKER *et al.* (2004). Data were collected from patients treated from 1997 to 2001 in a rural hospital, the *Centre Sanitaire et Nutrionnel Gbemoten*, Zagnanado (CSNG). In the Zou Region in 1999, BU had a higher detection rate (21.5/100,000) than leprosy (13.4/100,000) and tuberculosis (20.0/100,000). The percentage of nonulcerated and ulcerated forms was approximately 50 %. More than 13 % of the patients presented with osteomyelitis. Delay in seeking treatment declined from 4 months in 1989 to 1 month in 2001, and median hospitalization time decreased from 9 months in 1989 to 1 month in 2001. This reduction is attributed, in part, to the implementation of an international cooperation programme, the creation of a national BU programme, and making advances in patient care. These data showed that BU is highly endemic in southern Benin. This study also highlighted the importance of a multidisciplinary approach that involves educating the population, training healthcare workers, adequately managing cases, simplifying surgical procedures and microbiological confirmation of the cases. Two more recent studies performed in Benin by Johnson *et al.* (JOHNSON *et al.* 2005, JOHNSON *et al.* 2005) confirmed the large variation of distribution of BU at the village level in endemic areas.

The first case-control study on a large number of BU participants was also performed in Benin in 2003. The data showed that BU is mainly associated with age, place of residence and water sources. This study indicated that children < 15 years old are most at risk for BU and that the use of unprotected water is a risk factor of BU (DEBACKER *et al.* accepted).

In 2005, 1,045 patients were reported and > 50 % of the cases have been analysed by microbiological methods for confirmation of the cases (Johnson, personal communication).

4.3.2. Burkina Faso

In 1998, Ouoba *et al.* noted 6 patients with BU in Burkina Faso (OUOBA *et al.* 1998). Two of them, however, spent long periods of time in Ivory Coast. Several samples from clinically suspected cases were analysed in 2005 at the ITM but none of them was positive for *M. ulcerans*.

4.3.3. Cameroon

In 1973, Ravisse discovered 47 patients with BU in a focus in Cameroon, localized between Ayos and Akonolinga in a permanently swampy area. From this group of patients, 8 strains of *M. ulcerans* were isolated, confirming the presence of BU (RAVISSE 1977). Boisvert studied the bacteriology of the strains of *M. ulcerans* isolated from lesions in Cameroon (BOISVERT 1977).

During a cross-sectional survey conducted in the Nyong River basin in August 2001, 436 active or inactive cases were reported (NOESKE *et al.* 2004).

New cases have also been reported between 2002 and 2003 confirming that the disease is still endemic in Cameroon (World Health Organization 2004). Most of these cases were bacteriologically confirmed (NOESKE *et al.* 2004).

4.3.4. Ivory Coast

BU is an important re-emerging tropical disease in Ivory Coast. The first BU patient diagnosed in Ivory Coast was a 7-year-old French boy treated by Perraudin *et al.* in 1980 (PERRAUDIN *et al.* 1980). In 1984 Kouame reviewed all available information on BU for his doctoral thesis at the Medical Faculty of the

University of Abidjan. In 1990 Richard-Kadio *et al.* determined that a hydroelectric reservoir was related to the prevalence of the infection, and reviewed the epidemiology of BU in the country: in the south, Abidjan, Aboissa, Adiake; central area, Toumodi, Oumé, Yamoussoukro; centre-east, Daoukro; west, Daloa, Issia, Gagnoa, Man. They underlined the presence in Daloa and Daoukro of more than 80 cases; 7 of their own 18 patients were diagnosed in January 1990 (Richard-Kadio *et al.* 1990). This constituted a marked increase in incidence. In 1992, Cornet *et al.* reported on the surgical treatment of 50 BU patients, the majority under 14 years of age (Cornet *et al.* 1992). They remarked that two thirds of the patients had good cosmetic results, but that 20 % had functional disabilities and prolonged hospitalization that led to high costs.

In 1993, Darie *et al.* described 124 recent admissions for BU in the Dermatology Service of the *Centre Hospitalier Régional* at Bouake from 1990 to 1992 (67 males/44 children; 57 females/40 children) (Darie *et al.* 1993). Of the 124, 102 were inhabitants of 4 rural foci that arose after 1988: Bamoro, Lac de Kossou, Daoukro, and Daloa. Eighty-five percent had not been vaccinated with BCG, and the prevalence was not related to HIV infection. In 1994 Darie *et al.* outlined their therapeutic approaches to these patients (Darie *et al.* 1994). They associated the disease with rural activities and had good reason to suspect that pisciculture of tilapia played a role.

To investigate BU as an emerging disease in West Africa, Marston *et al.* in 1991 conducted a survey in rural areas of Ivory Coast and identified 312 active or healed ulcerations, with the highest rates in the age group 10 to 14 years and a nearly equal percentage for males and females (Marston *et al.* 1995). There was a threefold increase between 1987 and 1991, and local prevalence was as high as 16.3 %. Among the healed, functional disabilities were as high as 26 %. The risk factor for infection was farming activities near the river, with an incremental decrease in risk for each 10-minute walking distance between the fields and the river. Similar findings were described in Benin (Johnson *et al.* 2005).

A nationwide survey conducted in 1997 identified 10,382 cases, with a cumulative number of cases between 1978 and 2003 of approximately 17,000 (World Health Organization 2004).

The majority of these cases were identified clinically but were not confirmed by microbiological tests.

4.3.5. Ghana

In 1971 Bayley published a report of the first case of BU in Ghana, a patient treated at Korle Bu Hospital in Accra (Bayley 1971). Van der Werf *et al.*, based at Agogo Hospital in the Ashanti area, diagnosed the first patients with BU in that area in 1980 (Van der Werf *et al.* 1989). They were impressed by the rapid increase in the number of patients with ulcers and attempted to describe the spread of the disease. They retrospectively studied the 45 ulcers on record for 1981 to 1985 and an additional 51 ulcers in 1986 to 1987 by evaluating suspected lesions for the presence of AFB, and by culture and histopathologic findings. The patients came from the vicinity of the hospital and a remote rural community along the Afram River to the north of Agogo. Additional studies are essential to determine prevalence in the swampy area along Lake Volta. Amofah *et al.,* during a vaccination campaign, investigated the epidemiology of BU in Amansie West, one of the 18 Ashanti districts (AMOFAH *et al.* 1993). This was in a population of 130,000 living in a diverse environment of primeval tropical and secondary forests irrigated by the rivers Offim and Oda. In an extensive survey, they discovered 90 suspected cases (prevalence 1/1,500) in 33 of the 135 villages. Of these patients, 49 % were under 15 and 20 % over 50 years of age; males dominated in the younger groups and females among the adults. Peak incidence was in September and October.

Ulcers were less persistent in BCG-vaccinated persons, but BCG did not influence the age of onset. In 1998, Amofah *et al.* confirmed the efficacy of excision at the preulcerative stage in patients living in rural Ghana (AMOFAH *et al.* 1998). Of 50 patients treated by excision and suturing, the median healing time was 31.5 days with a recurrence rate at one year of 16 %. None had any deformity.

Asiedu and Etuaful investigated the socioeconomic impact of BU among impoverished rural inhabitants with an income of $310/capita/annum in Agogo, Amansie West in Ghana over a period of 3 years (1994 to 1996) (ASIEDU & ETUAFUL 1998). This retrospective study is based on 102 cases treated at St. Martin's Catholic Hospital of Agroyesum, Amansie West. The direct costs/patient/year (hospital stay, surgery, laboratory tests, drugs, dressings, and miscellaneous expenses), excluding staff costs, were established at $13,377 (US) in 1994, but declined to $4,466 (US) in 1996. The indirect costs (feeding, productivity losses, miscellaneous expenses) averaged $617 (US)/person/year in 1994 and $543 (US) in 1996. Compared to per capita earnings, these costs are astounding and will become more so as BU spreads in West Africa. Only early diagnosis and surgical excision can avoid prolonged hospitalization and permanent disabilities, and thus reduce expenses. In the meantime, the burden on the rural poor, in the absence of any welfare system other than the family, should be alleviated. This social perspective, although not based on firm scientific data, should stimulate the governments of endemic countries and/or international relief organizations to provide necessary subsidized care.

A nationwide survey was performed in 1999. Nearly 6,000 prevalent cases were identified in all 10 regions affected. Approximately 2,800 cases were reported between 2000 and 2003 (World Health Organization 2004). However, less than 20 % of the cases are presently confirmed by microbiological tests (Asiedu, personal communication).

4.3.6. Guinea

Recent unpublished observations suggest BU may be indigenous in Guinea. Surveys performed between 1993 and 2003 reported 489 clinically suspected cases (World Health Organization 2004). However, only two cases have been bacteriologically confirmed (Portaels, unpublished).

4.3.7. Liberia

Ziefer *et al.* at the AFIP made a fortuitous discovery of 2 *M. ulcerans* skin ulcerations in 1981 while conducting a survey on onchocerciasis in Liberia (Ziefer *et al.* 1981). The 2 boys reported were under treatment at the Swedish Pentecostal Mission Clinic at Foya Camara, one from Farawolu village, to the northeast, and the other from Laobengu to the south of this small town in Upper Lofa County, 250 km northeast of Monrovia and 10 km east of the border with Sierra Leone. The 8-year-old patient had a lesion on his right knee of several months duration, with AFB in smears. He was transferred to Curran Lutheran Hospital at Zorzor. The 11-year-old boy had been treated in 1977 for a lesion on the right arm at Curran Hospital and transferred to the Foya Camara clinic.

Histopathologic analyses of the lesions of each patient revealed diagnostic changes. An association with swampy terrain and agricultural activities was suggested. Monson *et al.* reported 4 more patients with BU, 3 of whom lived within a 6-km radius of Foya Camara (Monson *et al.* 1984). The other patient came from an area 150 km south of Foya Camara. Until now, no other cases have been reported from this country.

4.3.8. Nigeria

BU was established in Nigeria successively by Gray *et al.* 1967, Farber & Tsang 1967 and Oluwasanmi *et al.* 1976. The 4 cases reported by Gray originated in the savanna grassland in the Tiv District in Lower Benue Province. Gray was also aware that the disease prevailed in Upper Benue. Farber and Tsang reported BU in a Peace Corps worker returned from Nigeria.

In a classic paper on BU, Oluwasanmi *et al.* described a microepidemic of the disease in 22 patients among residents of the University of Ibadan (Oluwasanmi *et al.* 1976). This epidemic followed the damming of a stream to create a lake and a fishpond. Prior to the construction of the dam, no cases of BU had been recorded in this location. A few cases, bacteriologically confirmed at the ITM, were diagnosed in the Cross River State in 1999 and 2000, in collaboration with Sister Dr. M.A. Meyer. Patients from Nigeria were also sometimes treated in Benin (Debacker *et al.* 2004).

4.3.9. Sierra Leone

In their article on Liberia Monson *et al.* (1984) mention the presence of BU in neighbouring Sierra Leone. The only publication from Sierra Leone concerned a case detected in 1975 (World Health Organization 2004). No other cases have been reported from this country.

4.3.10. Togo

In 1996 Meyers *et al.* reported the first cases of BU in Togo in 2 children admitted for massive ulcerations at the *Hôpital St Jean de Dieu*, at Afagnan, Préfecture des Lacs (MEYERS *et al.* 1996). One was a 9-year-old boy from Kpomé-Kpota, Préfecture Vo, with a massive ulcer on his leg. This lesion followed a penetrating wound by a splinter of wood, sustained while the boy was visiting his father who lived along the Haho River. Exudates from the lesion contained AFB. The other patient, a 9-year-old girl from Adon-Konji, had a massive edematous lesion on the right scapula, back, and flank. Exudates were positive for AFB. She had been working in gardens along the Togo bank of the Mono River. *M. ulcerans* was identified in both patients by DNA studies. The histopathologic changes were typical of BU, including the presence of AFB. The Togo cases completed the geographic continuity of BU from Uganda in the east to Guinea in the west. Bacteriologically confirmed cases have come mainly from the Maritime Region in the south (World Health Organization 2004; Portaels, unpublished).

5. The Expanding Distribution of *M. ulcerans* Worldwide

5.1. SOUTHEAST ASIA

5.1.1. Kiribati

In 1987 Christie reported suspected *M. ulcerans* infections in the West Central Pacific atoll nation of Kiribati, but identification of the etiologic agent was not established (CHRISTIE 1987).

5.1.2. Malaysia

Tropical phagedenic ulcers have long been a problem in Malaysia. In 1925, at Kuala Lumpur, the Malaysian Institute for Medical Research recorded 528 cases, mostly in labourers. In 1954 there was an outbreak of undermined ulcers in children in the vicinity of Malacca, but AFB were not reported in the ulcers. Pettit *et al.*, however, described the following infections in Malaysia in 1966 (PETTIT *et al.* 1966).

In the 1960s, *M. ulcerans* infection was suspected by Bolton, Medical Officer in charge of the Aboriginal Health Service. A 5-year-old girl (Case 1) was hospitalized in November 1964 for an ulceration with undermined edges over her right patella. This was a relapse of 2 ulcerated nodules which had healed 2 years earlier. Her 3-year-old brother (Case 2) was admitted at the same time with diarrhoea and received parenteral infusions. An ulcer with undermined edges and containing AFB developed at the site of the infusion. Treatment with 100 mg B663 (clofazimine) daily healed this ulcer in 5 weeks. The boy probably acquired the infection from his sister while sleeping in a common family bed.

Case 3 was an Indian boy, aged 4, hospitalized in Kuala Lipis Hospital (Pahang State), where he had been hospitalized in 1962 for a chronic ulceration on his right leg. He was taken home by his parents but returned in August 1963 with a massive ulceration around the knee, ankle, and foot, requiring amputation. In 1964, however, an indurated nodule appeared on the left arm accompanied by edema extending over the forearm and hand. An ulcer developed at the biopsy site and became progressive. The histopathologic changes were thought to represent tuberculosis; however, even though the lesion was rich in AFB, culture at 37 °C was not successful and antituberculosis treatment failed. Ulceration extended and *M. ulcerans* was suspected. B663 treatment for 6 months cured the patient.

Case 4 was a 27-year-old aboriginal woman who, 12 days after the delivery of a baby, developed cellulitis over the head of the fibula, which became fluctuant and ulcerated. The pus contained AFB and staphylococci.

At the National Institute for Medical Research at Mill Hill, London, a homogenate of a biopsy specimen of skin of Case 1 produced growth at 31 to 33 °C after 10 weeks. Inoculation in mouse footpads produced lesions after 3 to 4 months. Although mouse inoculations failed in Cases 2 and 3, Case 4 was positive. The 3 strains now available were sensitive *in vitro* to B663. This sensitivity was confirmed in mice treated daily. On suspicion that *M. ulcerans* may have produced the necrotic ulcer of Case 4, B663 was administered with good results.

In conclusion, these 4 patients from a rather swampy area in central Malaysia were the first *M. ulcerans* infections reported in Malaysia and Southeast Asia. The surprisingly successful B663 treatment should be noted because this drug has not proved useful in some other geographic areas (Revill *et al.* 1973).

There have been mention of unrecorded outbreaks in the past, but no recently confirmed cases have been registered so far (World Health Organization 2004).

5.1.3. Sri Lanka (Ceylon)

In 1992 Seevanayagam and Hayman published a provocative report concerning the possible existence of BU in Sri Lanka (Seevanayagam & Hayman 1992). There is however no convincing evidence for BU in Sri Lanka, nor anywhere in the Indian subcontinent. Furthermore, the concept of the Gondwanian distribution of *M. ulcerans* (Hayman 1984) seems to have no basis in fact. Recently, based on results of genetic analysis of *M. ulcerans* and *M. marinum* (Stinear *et al.* 2000). Hayman refuted this hypothesis and claimed that *M. ulcerans* is of recent evolution (Hayman 2005).

5.1.4. Indonesia

From 1960 to 1964, Shattock, a surgeon at Wingfoot Hospital on North Sumatra, observed 5 patients with mycobacterial skin ulcerations (Shattock 1965). One of these, a 21-year-old Indonesian, had an infection that was well documented and photographed. Over a 5-month period, an ulceration 12 × 12 cm developed on the upper arm. Clinical findings and development were compatible with BU, but AFB were not ascertained.

5.2. The Western Hemisphere

5.2.1. French Guiana

Pradinaud *et al.* reported 23 patients with cutaneous mycobacterioses, of which 20 were described at the World Congress of the International Society of Tropical Dermatology in São Paulo, Brazil in 1974 (Pradinaud *et al.* 1974). The first case (1969) was a child of 2 years who developed an ulceration of the skin on the left knee typical of Buruli ulcer. AFB were detected in all cases, but the first culture of *M. ulcerans* was from Case 17 and was identified at the *Institut Pasteur de Lille*. At the *Centre Hospitalier Universitaire d'Angers*, De Gentile *et al.* observed a carpenter of French nationality with 10 years service in French Guiana (De Gentile *et al.* 1992). Just prior to his illness, he had gone to work in the east at Oianary and Trois Sauts, where he bathed in a small creek. He developed a small painless nodule on the antero-external side of his left thigh that ulcerated. Although no leishmania were demonstrated in the lesion, he had previously suffered from cutaneous leishmaniasis and was treated with pentamidine, but to no avail. He then treated the lesion himself with a Creole remedy. When a second ulcer appeared near the first, he sought medical help in France. The undermined edges of the ulcer and the absence of adenopathy prompted a search for *M. ulcerans*. AFB were present in the smear. Cultivation in a variety of media and temperatures was successful after 6 weeks on a diphasic medium and easily subcultivated on Löwenstein-Jensen medium. Inoculation in rats and mice produced lesions in the feet, ears, and tail. The diagnosis was confirmed at the *Institut Pasteur Paris*. This was the first BU reported inland in French Guiana; infection is most frequent in the coastal region. In 1998 Pradinaud *et al.* presented 132 cases in French Guiana (67 men, 65 women; 73 < 20 years of age) (Pradinaud *et al.* 1998). The ethnic distribution was Creole 64 %, Galibi Indian 17 %, Caucasian 14 %, Chinese and Laotian 5 %. As in Africa, ulcers thrived in remote areas among the poor with little access to health facilities, transportation, or clinicians trained in the diagnosis of BU.

The cumulative number of cases between 1969 and 2003 was 195 and the incidence rate remained stable over time with an average of 5 cases per 100,000 inhabitants (World Health Organization 2004).

5.2.2. Mexico

The detection of a nonleprous mycobacterial skin ulcer in 1953 by Lavalle Aguilar was the first sign of BU in the New World (Lavalle Aguilar 1953). At the 6th International Leprosy Congress, Lavalle Aguilar reported an ulceration on the left hand of a 30-year-old *campesino* living at Atapán, Hidalgo State, in the centre of eastern Mexico. The ulcer was undermined and contained AFB shown by Middlebrook and Schaeffer to be *M. ulcerans*.

In 1981, 28 years later, the same dermatologist discovered a second BU in an 11-year-old schoolboy living at Tapatán (Acaxochitlan), also in Hidalgo State.

The large ulceration on the back of the right hand and wrist followed an injury from a fall. The diagnosis was confirmed by clinical, histopathological and bacteriological data. The identity of *M. ulcerans* was confirmed and the lesion excised. The PPD test was positive and the lepromin test ulcerated. Healing followed cleaning in a copper sulfate solution of 1 part/1,000, and DDS and rifampin administration. BU remains rare in Mexico with only 8 cases reported from 1953 until 2005 (Novales-Santa Coloma 2005).

5.2.3. Peru

In 1969 Gallarday-Vásquez *et al.* reported 2 patients originating in the Huallaga Basin in the Amazonia Peruana (Gallarday-Vasquez *et al.* 1969). Case 1 was a soldier, 20 years old, from the district of Navarro. He had extensive necrotic ulceration that began as a slowly growing nodule. The Mantoux test was negative. AFB from the lesion did not infect guinea-pigs; however, *M. ulcerans* was cultivated on artificial media. Case 2 was an 18-year-old male from Cerro de Pacco, who moved from Tango María to Lima. By smear, histopathology, and bacteriology, his cutaneous ulceration was confirmed as BU. Both diagnoses were made in the Dermatology Department of the *Hospital Militar Central.* Saldana-Patino, in 1988, reported a third patient, a civilian evacuated from the *Hospital Regional San Rosa de Iquitos* to the military hospital in Lima (Saldana-Patino 1988). He reviewed specimens from 1,620 ulcers examined between 1969 and 1981 and found no other patients. All 3 of these patients were from the Amazonia Peruana, and had been in contact with tributaries of the Amazon River. From 1996 to 2005, 9 additional cases confirmed by microbiological analyses were found in Peru. Six patients came from the Peruvian rain forest and 3 were infected in the north coast of Peru (Guerra *et al.*, in preparation).

5.2.4. Suriname

Cases from Suriname have been recorded in French Guiana (World Health Organization 2004).

Microbiological analyses performed at the ITM confirmed another BU case in a patient from Suriname who was treated in Amsterdam. Molecular analyses confirmed that the isolate was *M. ulcerans* (Portaels 1996) and that it was identical to the isolates from French Guiana (Stragier *et al.* 2005).

5.3. The Far East

5.3.1. China

The first case of BU was reported in 2000 in a Chinese woman who had travelled in 1997 to Ri Zao City in San Dong Province. Molecular analyses identified the mycobacterium as *M. ulcerans* subspecies *shinshuense* (Faber *et al.* 2000). Two other cases clinically diagnosed by Dr Xuelu Zhou were reported in 2001 and 2003 (World Health Organization 2004). One case was confirmed by PCR at the ITM.

5.3.2. Japan

In 1989 Tsukamura *et al.* published a taxonomic study on a mycobacterium isolated from a Japanese girl with a skin lesion quite similar to Buruli ulcer (Tsukamura *et al.* 1989). This organism was named *M. shinshuense*; however, further studies by Portaels *et al.* placed the mycobacterium in the *M. ulcerans* group (Portaels *et al.* 1996). A second case of *M. shinshuense* infection was reported in 2004 (Kazumi *et al.* 2004).

6. Conclusions

Over the last half of the 20th century (1948 to 1999), the importance of the often disabling and sometimes fatal *M. ulcerans* skin infection has been established worldwide. The clinical symptoms are usually unique and the histopathologic changes convincing: undermined cutaneous ulcers with extensive necrosis of the fatty tissue and presence of AFB.

The identification and bacteriology of *M. ulcerans,* one of many atypical mycobacteria, has been patiently worked out by classical cultural methods and animal inoculation. But the new tools provided by molecular biology have greatly increased our capacity to detect the infection, and sources of and modes of transmission of the etiologic agent (Portaels *et al.* 1996, 1997, 1999, 2001; Stragier *et al.* 2005, 2006). Thanks to these microbiological tools, cases have been confirmed in several countries where foci of the disease have been recently rediscovered (DRC, Angola, Gabon, Cameroon, Nigeria, Uganda, Japan, Mexico and Peru) and where new foci have recently been confirmed (Equatorial Guinea, Togo, Guinea, Sudan and China). Some countries clearly have difficulties with the clinical identification of cases and/or the collection of appropriate specimens for laboratory tests. Consequently, the number of declared BU cases may be overestimated, and worse, management of patients with diseases other than BU can be totally inadequate. In countries where the disease has been endemic for decades (*e.g.* Benin, Ivory Coast and Ghana), the clinical diagnosis of BU may be correct for most of the cases since health professionals dealing with BU are highly experienced. Laboratory confirmation of BU cases remains, however, essential for the determination of the true prevalence and incidence of the disease in a given area and for confirmation of new foci.

Epidemiologic studies established quite early that the disease was related to wetlands. For unknown reasons, from current surveys, the prevalence of BU in Uganda seems to have diminished significantly. However, changing environmental factors, such as the irregular rise and fall of water levels in Central African lakes, could be important. Given what we have learned of the epidemiology of BU, all who live within foci of the infection should be mindful of any ecological changes attributable to water management, for example, for agricultural purposes, mining enterprises, or energy production. For further details, the reader is referred to an earlier review by Prof. Janssens in 1972 (Janssens 1972).

It is hoped that this historical overview, while not comprehensive, can provide practical insights, and perhaps some prognostications.

ACKNOWLEDGEMENTS

Financial support was in part provided by the Damien Foundation and the DGDC (Directorate General for Development and Cooperation), Belgium.

We thank Gladys Anyo, Karin Janssens and E. Meyers for outstanding assistance in the preparation of the manuscript. Bonnie Casey (American Registry of Pathology at the AFIP) also provided editorial assistance for portions of the manuscript.

This review is dedicated to patients suffering from Buruli Ulcer, and to health professionals for their devoted care of patients and diligent research.

REFERENCES

Aguiar, J., Domingo, M. C., Guedenon, A., Meyers, W. M., Steunou, C. & Portaels, F. 1997. Buruli ulcer: an important re-emerging mycobacterial disease in Benin [in French]. — *Bull. Séanc. Acad. R. Sci. Outre-Mer*, **43**: 325-358.

Aguiar, J. & Steunou, C. 1997. Buruli ulcer in rural areas of Benin: management of 635 cases [in French]. — *Méd. Trop.* (Mars), **57**: 83-90.

Amofah, G., Asamoah, S. & Afram-Gyening, C. 1998. Effectiveness of excision of pre-ulcerative Buruli lesions in field situations in a rural district in Ghana. — *Trop. Doct.*, **28**: 81-83.

Amofah, G. K., Sagoe-Moses, C., Adjei-Acquah, C. & Frimpong, E. H. 1993. Epidemiology of Buruli ulcer in Amansie West district, Ghana. — *Trans. R. Soc. Trop. Med. Hyg.*, **87**: 644-645.

Andersen, F. O. 1965. Mycobacterial skin ulcers. Clinical experience. — *Cent. Afr. J. Med.,* **11**: 131-135.

Asiedu, K. & Etuaful, S. 1998. Socioeconomic implications of Buruli ulcer in Ghana: a three-year review. — *Am. J. Trop. Med. Hyg.*, **59**: 1015-1022.

Aujoulat, I., Huguet-Ribas, M. P. & Koita, Y. 1996. Buruli ulcer: an ignored public health problem [in French]. — *Dev. Santé.*, **125**: 22-30.

Bar, W., Rusch-Gerdes, S., Richter, E. *et al.* 1998. *Mycobacterium ulcerans* infection in a child from Angola: diagnosis by direct detection and culture. — *Trop. Med. Int. Health*, **3**: 189-196.

Barker, D. J. P. 1971. Buruli disease in a district in Uganda. — *J. Trop. Med. Hyg.*, **74**: 260-264.

Barker, D. J. P. 1972. The distribution of Buruli disease in Uganda. — *Trans. R. Soc. Trop. Med. Hyg.*, **66**: 867-874.

Barker, D. J. P., Clancey, J. K. & Rao, S. K. 1972. Mycobacteria of vegetation in Uganda. — *East. Afr. Med. J.*, **49**: 667-671.

Barker, D. J. & Ninkibigaya, V. 1972. Buruli disease and patients' activities. — *East. Afr. Med. J.*, **49**: 260-268.

Barker, D. J. P. 1973. Epidemiology of *Mycobacterium ulcerans* infection. — *Trans. R. Soc. Trop. Med. Hyg.,* **67**: 43-50.

BARKER, D. J. P. 1974. Microbacterial skin ulcers. — *Br. J. Dermatol.*, **91**: 473-474.

BAYLEY, A. C. 1971. Buruli ulcer in Ghana. — *Br. Med. J.*, **2**: 401-402.

BOISVERT, H. 1977. Skin ulcer caused by *Mycobacterium ulcerans* in Cameroon. II. Bacteriological study [in French]. — *Bull. Soc. Pathol. Exot. Filiales*, **70**: 125-131.

BUCKLE, G. 1972. Notes on *Mycobacterium ulcerans*. — *Aust. N. Z. .J Surg.*, **41**: 320-323.

BURCHARD, G. D. & BIERTHER, M. 1985. Buruli ulcer: clinical pathological study of 23 patients in Lambaréné, Gabon. — *Trop. Med. Parasitol.*, **37**: 1-8.

CARAYON, A., PERQUIS, P., HONORAT, M. & BLIN, F. 1968. Ulcers due to mycobacteria in Africa [in French]. — *Bull. Soc. Méd. Afr. Noire Lang. Fr.*, **13**: 670-679.

CHRISTIE, M. 1987. Suspected *Mycobacterium ulcerans* disease in Kiribati. — *Med. J. Aust.*, **146**: 600-604.

CLANCEY, J. K., DODGE, O. G., LUNN, H. F. & ODUORI, M. L. 1961. Mycobacterial skin ulcers in Uganda. — *Lancet*, **2**: 951-954.

CONNOR, D. H. & LUNN, H. F. 1966. Buruli ulceration. A clinicopathologic study of 38 Ugandans with *Mycobacterium ulcerans* ulceration. — *Arch. Pathol.*, **81**: 183-199.

CORNET, L., RICHARD-KADIO, M., N'GUESSAN, H. A. *et al.* 1992. Treatment of Buruli ulcer by excision-graft [in French]. — *Bull. Soc. Pathol. Exot.*, **85**: 355-358.

DARIE, H., DJAKEAUX, S. & CAUTOCLAUD, A. 1994. Therapeutic approach in *Mycobacterium ulcerans* infections [in French]. — *Bull. Soc. Pathol. Exot.*, **87**: 19-21.

DARIE, H., LE GUYADEC, T. & TOUZE, J. E. 1993. Epidemiological and clinical aspects of Buruli ulcer in Ivory Coast. 124 recent cases [in French]. — *Bull. Soc. Pathol. Exot.*, **86**: 272-276.

DAWSON, D. J. 1974. The bacteriology of *Mycobacterium ulcerans* disease. — *P.N.G. Med. J.*, **17**: 157-159.

DEBACKER, M., AGUIAR, J., STEUNOU, C., ZINSOU, C., MEYERS, W. M., GUEDENON, A., SCOTT, J. T., DRAMAIX, M. & PORTAELS, F. 2004. *Mycobacterium ulcerans* Disease (Buruli ulcer) in a Rural Hospital, Southern Benin, 1997-2001. — *Emerg. Infect. Dis.*, **10**: 1391-1398.

DEBACKER, M., PORTAELS, F., AGUIAR, J., STEUNOU, C., ZINSOU, C., MEYERS, W. M. & DRAMAIX, M. Risk factors for *Mycobacterium ulcerans* disease (Buruli ulcer): a case-control study in Benin. — *Emerg. Infect. Dis.* (accepted).

DE BERGEYCK, E., JANSSENS, P. G. & DE MUYNCK, A. 1980. Radiological abnormalities of the ileum associated with the use of clofazimine (Lamprene; B663) in the treatment of skin ulceration due to *Mycobacterium ulcerans*. — *Lepr. Rev.*, **51**: 221-228.

DE GENTILE, P. L., MAHAZA, C., ROLLAND, F., CARBONNELLE, B., VERRET, J. L. & CHABASSE, D. 1992. Cutaneous ulcer due to *Mycobacterium ulcerans*. A propos of 1 case in French Guiana [in French]. — *Bull. Soc. Pathol. Exot.*, **85**: 212-214.

DODGE, O. G. & LUNN, H. F. 1962. Buruli ulcer: a mycobacterial skin ulcer in a Ugandan child. — *J. Trop. Med. Hyg.*, **65**: 139-142.

FABER, W. R., PEREIRA ARIAS-BOUNDA, L. M., ZEEGELAAR, J. E., KOLK, A. H. J., FONTEYNE, P.-A., TOONSTRA, J. & PORTAELS, F. 2000. First case of *Mycobacterium ulcerans* infection in the Peoples Republic of China. — *Trans. Roy. Soc. Trop. Med. Hyg.*, **94**: 277-279.

FARBER, E. R. & TSANG, A. 1967. Mycobacterial ("Buruli") ulcer in a Peace Corps worker. — *Arch. Surg.*, **95**: 297-300.

FENNER, F. 1974. The "Bairnsdale bacillus": *Mycobacterium ulcerans*. — *P.N.G. Med. J.*, **17**: 126-149.

FLOOD, P. E, STREET, A., O'BRIEN, P. & HAYMAN, J. A. 1994. *Mycobacterium ulcerans* infection on Phillip Island, Victoria. — *Med. J. Aust.*, **160**: 160.

GALLARDAY-VASQUEZ, R., GAJATE-GEANINI, A., CHAVEZ, J. M., SALDANA-PATINO, J. & RUIZ-MENACHO, A. 1969. First cases of Buruli ulcer in Peru [in Spanish]. — *Rev. San. Mil. Peru.*, **17**: 59-74.

GRAY, H. H., KINGMA, S. & KOK, S. H. 1967. Mycobacterial skin ulcers in Nigeria. — *Trans. R. Soc. Trop. Med. Hyg.*, **61**: 712-714.

HAYMAN, J. 1984. *Mycobacterium ulcerans*: an infection from Jurassic time? — *Lancet*, **2**: 1015-1016.

HAYMAN, J. 1987. *Mycobacterium ulcerans* infection in Victoria: celebration of a golden jubilee? — *Australas J. Dermatol.*, **28**: 99-105.

HAYMAN, J. A. 2005. A hypothesis refuted: *Mycobacterium ulcerans* is of recent evolution. — *The Lancet*, **5**: 327-328.

HENNEBERT, P. N., GATTI, F., VANDEPITTE, J. & PATTYN, S. R. 1962. Two cases of necrotic ulcer caused by acid-fast bacilli observed in Leopoldville [in French]. — *Ann. Soc. Belg. Méd. Trop.*, **42**: 549-553.

HOCKMEYER, W. T., KRIEG, R. E., REICH, M. & JOHNSON, R. D. 1978. Further characterization of *Mycobacterium ulcerans* toxin. — *Infect. Immun.*, **21**: 124-128.

IGO, J. D. & MURTHY, D. P. 1988. *Mycobacterium ulcerans* infections in Papua New Guinea: correlation of clinical, histological, and microbiological features. — *Am. J. Trop. Med. Hyg.*, **38**:391-392.

JANSSENS, P. G. 1972. Skin ulcers caused by acid-fast bacilli. — *In*: MARSHALL, J. (Ed.), Essays on Tropical Dermatology. Amsterdam, the Netherlands, Excerpta Medica, pp. 264-295.

JANSSENS, P. G., QUERTINMONT, M. J., SIENIAWSKI, J. & GATTI, F. 1959. Necrotic tropical ulcers and mycobacterial causative agents. — *Trop. Geogr. Med.*, **11**: 293-312.

JOHNSON, P. D., VEITCH, M. G., FLOOD, P. E. & HAYMAN, J. A. 1995. *Mycobacterium ulcerans* infection on Phillip Island, Victoria. — *Med. J. Aust.*, **162**: 221-222.

JOHNSON, P. D., VEITCH, M. G., LESLIE, D. E., FLOOD, P. E. & HAYMAN, J. A. 1996. The emergence of *Mycobacterium ulcerans* infection near Melbourne. — *Med. J. Aust.*, **164**: 76-78.

JOHNSON, P. D. R., STINEAR, T., SMALL, P. L. C., PLUSCHKE, G., MERRITT, R. W., PORTAELS, F., HUYGEN, K., HAYMAN, J. A. & ASIEDU, K. 2005. Buruli ulcer (*M. ulcerans* infection): New insights, new hope for disease control. — *PLOS Med.*, **2**: 282-286.

JOHNSON, R. C., MAKOUTODE, M., SOPOH, G. E., ELSEN, P., GBOVI, J., POUTEAU, L. H., MEYERS, W. M., BOKO, M. & PORTAELS, F. 2005. Buruli ulcer in Benin. — *Emerg. Infect. Dis.*, **11**: 500-501.

JOHNSON, R. C., SOPOH, G. E., BOKO, M., ZINSOU, C., GBOVI, J., MAKOUTODE, M. & PORTAELS, F. 2005. Distribution de l'infection à *Mycobacterium ulcerans* (ulcère de Buruli) dans la commune de Lalo au Bénin. — *Trop. Med. Int. Health*, **10**: 863-871.

JOSSE, R., GUEDENON, A., AGUIAR, J. *et al.* 1994. Buruli ulcer, a pathology little known in Benin. A propos of 227 cases [in French]. — *Bull. Soc. Pathol. Exot.*, **87**: 170-175.

KAZUMI, Y., OHTOMO, K., TAKAHASHI, M., MITARAI, S., SUGAWARA, I., IZUMI, J., ANDOH, A. & HASEGAWA, H. 2004. *Mycobacterium shinshuense* isolated from cutaneous ulcer lesion of right lower extremity in a 37-year-old woman [in Japanese]. — *Kekkaku*, **79**: 437-441.

KIBADI, K. A., SINGA NYOTA, J., WEMBANYAMA, H. & PORTAELS, F. 2006. Résultats de l'enquête nationale préliminaire sur l'ulcère de Buruli en République Démocratique du Congo. — *Bull. ALLF,* **18**: 24-26.

LAVALLE AGUILAR, P. 1953. Human infection due to *Mycobacterium ulcerans* (Bairnsdale disease) in Western Hemisphere; preliminary note [in Spanish]. — *Int. J. Lepr.,* **21**: 469-476.

LUNN, H. F., CONNOR, D. H., WILKS, N. E. *et al.* 1965. Buruli (mycobacterial) ulceration in Uganda. A new focus of Buruli ulcer in the Madi District, Uganda: report of a field study. — *East Afr. Med. J.,* **42**: 275-288.

LYTTON, D. G. & LAVETT, J. 1974. The pathology of the *Mycobacterium ulcerans* infection in Papua New Guinea. — *P.N.G. Med. J.*, **17**: 150-159.

MACCALLUM, P., TOLHURST, J. C., BUCKLE, G. & SISSONS, H. A. 1948. New mycobacterial infection in man. — *J. Pathol. Bacteriol.*, **60**: 93-122.

MARSTON, B. J., DIALLO, M. O., HORSBURGH, C. R. Jr. *et al.* 1995. Emergence of Buruli ulcer disease in the Daloa region of Côte d'Ivoire. — *Am. J. Trop. Med. Hyg.*, **52**: 219-224.

MELENEY, F. L. & JOHNSON, B. A. 1950. Supplementary report on a case of chronic ulceration of the foot due to a new pathogenic mycobacterium (MacCallum). — *Ann. Soc. Belg. Méd. Trop.*, **30**: 1499-1504.

MEYERS, W. M. 1975. Residence of first patient with *Mycobacterium ulcerans* infection in Zaire [letter]. — *Ann. Soc. Belg. Méd. Trop.*, **55**: 125.

MEYERS, W. M., CONNOR, D. H., MCCULLOUGH, B., BOURLAND, J., MORIS, R. & PROOS, L. 1974. Distribution of *Mycobacterium ulcerans* infections in Zaire, including the report of new foci. — *Ann. Soc. Belg. Méd. Trop.*, **54**: 147-157.

MEYERS, W. M., TIGNOKPA, N., PRIULI, G. B. & PORTAELS, F. 1996. *Mycobacterium ulcerans* infection (Buruli ulcer): first reported patients in Togo. — *Br. J. Dermatol.*, **134**: 1116-1121.

MITCHELL, P. J., JERRETT, I. V. & SLEE, K. J. 1984. Skin ulcers caused by *Mycobacterium ulcerans* in koalas near Bairnsdale, Australia. — *Pathology*, **16**: 256-260.

MONSON, M. H., GIBSON, D. W., CONNOR, D. H., KAPPES, R. & HIENZ, H. A. 1984. *Mycobacterium ulcerans* in Liberia: a clinicopathologic study of 6 patients with Buruli ulcer. — *Acta Trop.,* **41**: 165-172.

MUELDER, K. 1988. Buruli ulcer in Benin. — *Trop. Doct.*, **18**: 53.

MUELDER, K. & NOUROU, A. 1990. Buruli ulcer in Benin. — *Lancet*, **336**: 1109-1111.

NOESKE, J., KUABAN, C., RONDINI, S., SORLIN, P., CIAFFI, L., MBUAGBAW, J., PORTAELS, F. & PLUSCHKE, G. 2004. Buruli ulcer disease in Cameroon – rediscovered. — *Am. J. Trop. Med. Hyg.*, **70**: 520-526.

NOVALES-SANTA COLOMA, J., NAVARRETE-FRANCO, G., IRIBE, P. & LOPEZ-CEPEDA, L. D. 2005. Ulcerative cutaneous mycobacteriosis due to *Mycobacterium ulcerans*: Report of two Mexican cases. — *Int. J. Lepr.*, **73**: 5-12.

OLUWASANMI, J. O., SOLANKE, T. F., OLURIN, E. O., ITAYEMI, S. O., ALABI, G. O. & LUCAS, A. O. 1976. *Mycobacterium ulcerans* (Buruli) skin ulceration in Nigeria. — *Am. J. Trop. Med. Hyg.,* **25**: 122-128.

OUOBA, K., SANO, D., TRAORE, A., OUEDRAOGO, R., SAKANDE, B. & SANOU, A. 1998. Buruli ulcer in Burkina Faso: A propos of 6 cases [in French]. — *Tunis Med.*, **76**: 46-50.

PATTYN, S. R. 1961. Ulcers caused by acid-fast bacilli. A review, relative to a patient diagnosed in Elisabethville [in French]. — *Ann. Soc. Belg. Méd. Trop.*, **31**: 145-152.

PERQUIS, P. & MURET, G. 1965. Tropical skin ulcers due to mycobacteria [in French]. — *Bull. Soc. Pathol. Exot. Filiales*, **58**: 789-795.

PERRAUDIN, M. L., HERRAULT, A. & DESBOIS, J. C. 1980. *Mycobacterium ulcerans* skin ulcers (or Buruli ulcer) (author's translation) [in French]. — *Ann. Pédiatr.* (Paris), **27**: 687-692.

PETTIT, J. H., MARCHETTE, N. J. & REES, R. J. 1966. *Mycobacterium ulcerans* infection: clinical and bacteriological study of the first cases recognized in South East Asia. — *Br. J. Dermatol.*, **78**: 187-197.

PHANZU, M. D., BAFENDE, A. E., DUNDA, K. B., IMPOSO, D. B. B., KIBADI, K., NSIANGANA, Z. S., SINGA, N. J., MEYERS, W. M., SUYKERBUYK, P. & PORTAELS, F.. *Mycobacterium ulcerans* disease (Buruli Ulcer) in a rural hospital in Bas-Congo, 2002-2004, Democratic Republic of Congo. — *Amer. J. Trop. Med. Hyg.* (accepted).

PORTAELS, F. 1989. Epidemiology of ulcers due to *Mycobacterium ulcerans* [in French]. — *Ann. Soc. Belg. Méd. Trop.*, **69**: 91-103.

PORTAELS, F., FONTEYNE, P. A., DE BEENHOUWER, H. *et al.* 1996. Variability in 3' end of 16S rRNA sequence of *Mycobacterium ulcerans* is related to geographic origin of isolates. — *J. Clin. Microbiol.*, **34**: 962-965.

PORTAELS, F., AGUIAR, J., FISSETTE, K. *et al.* 1997. Direct detection and identification of *Mycobacterium ulcerans* in clinical specimens by PCR and oligonucleotide-specific capture plate hybridization. — *J. Clin. Microbiol.*, **35**: 1097-1100.

PORTAELS, F., ELSEN, P., GUIMARAES-PERES, A., FONTEYNE, P.-A. & MEYERS, W. M. 1999. Insects in the transmission of *Mycobacterium ulcerans* infection (Buruli ulcer). — *Lancet*, **353**: 986.

PORTAELS, F., CHEMLAL, K., ELSEN, P., JOHNSON, P. D. R., HAYMAN, J. A., KIRKWOOD, R. & MEYERS, W. M. 2001. *Mycobacterium ulcerans* in wild animals. — *In*: COLLINS, M. T. & MANNING, B. (Eds.), Mycobacterial infections in domestic and wild animals. Office International des Epizooties. *Scientific and Technical Review*, **20**: 252-264.

PRADINAUD, R., BASSET, A. & GROSSHANS, E. 1974. Twenty cases of mycobacterial skin infections in French Guiana [in French]. — *Castellania*, **2**: 273-274.

PRADINAUD, R., COUPPIE, P., CLYTI, E., GABAUDAN, M., LABOUCHE, M. & SAINTE-MARIE, D. 1998. French Guiana: the main focus in Americas for cutaneous ulcers caused by *Mycobacterium ulcerans*. — *In*: Yamoussoukro International Conference on Buruli Ulcer. Geneva, Switzerland, World Health Organization.

PSZOLLA, N., SARKAR, M. R., STRECKER, W., KERN, P., KINZL, L., MEYERS, W. M. & PORTAELS, F. 2003. Buruli Ulcer – a systemic disease. — *Clin. Inf. Dis.*, **37**: 78-82.

QUINN, J. V. & CROTTY, J. M. 1963. *Mycobacterium ulcerans* infection in the Northern Territory. — *Med. J. Aust.*, **2**: 317-319.

RADFORD, A. J. 1974. *Mycobacterium ulcerans*: a review. I. Epidemiology. II. Clinical presentation, histopathology, treatment and prevention. — *P.N.G. Med. J.*, **17**: 129-144.

RADFORD, A. J. 1974. *Mycobacterium ulcerans* infections in Papua New Guinea. — *P.N.G. Med. J.*, **17**:145-149.

RAVISSE, P. 1977. Skin ulcer caused by *Mycobacterium ulcerans* in Cameroon. I. Clinical, epidemiological and histological study [in French]. — *Bull. Soc. Pathol. Exot. Filiales,* **70**: 109-124.

Read, J. K., Heggie, C. M., Meyers, W. M. & Connor, D. H. 1974. Cytotoxic activity of *Mycobacterium ulcerans*. — *Infect. Immun.*, **9**: 1114-1122.

Reid, I. S. 1967. *Mycobacterium ulcerans* infection: a report of 13 cases at the Port Moresby General Hospital, Papua. — *Med. J. Aust.*, **1**: 427-431.

Revill, W. D., Morrow, R. H. & Pike, M. C. *et al.* 1973. A controlled trial of the treatment of *Mycobacterium ulcerans* infection with clofazimine. — *Lancet*, **2**: 873-877.

Richard-Kadio, M., Dick, R., Djeha, D. *et al.* 1990. Cutaneous ulcers caused by atypical mycobacteria and their treatment by plastic surgery [in French]. — *Méd. Afr. Noire Lang. Fr.*, **37**: 276-282.

Saldana-Patino, J. 1988. First cases of Buruli ulcer in Peru [in Spanish]. — *Acta Med. Peru*, **5**: 55-74.

Seevanayagam, S. & Hayman, J. 1992. *Mycobacterium ulcerans* infection: is the "Bairnsdale ulcer" also a Ceylonese disease? — *Ceylon Med. J.*, **37**:125-127.

Shattock, F. M. 1965. Mycobacterial skin ulceration [letter]. — *East Afr. Med. J.*, **43**: 548-551.

Smith, J. H. 1970. Epidemiologic observations on cases of Buruli ulcer seen in a hospital in the Lower Congo. — *Am. J. Trop. Med. Hyg.*, **19**: 657-663.

Stinear, T. P., Jenkin, G. A., Johnson, P. D. & Davies, J. K. 2000. Comparative genetic analysis of *Mycobacterium ulcerans* and *Mycobacterium marinum* reveals evidence of recent divergence. — *J. Bacteriol.*, **182**: 6322-6330.

Stragier, P., Ablordey, A., Meyers, W. M. & Portaels, F. 2005. Genotyping *Mycobacterium ulcerans* and *Mycobacterium marinum* using mycobacterial interspersed repetitive units. — *J. Bacteriol*, **187**: 1639-1647.

Stragier, P., Ablordey, A., Bayonne, L. M., Lugor, Y. L., Sindani, I. S., Suykerbuyk, P., Wabinga, H., Meyers, W. M. & Portaels, F. 2006. Heterogeneity among *Mycobacterium ulcerans* isolates from Africa. — *Emerg. Infect. Dis.*, **12**: 844-847.

Timpe, A. & Runyon, E. H. 1954. Relationship of "atypical" acid-fast bacilli to human disease: preliminary report. — *J. Lab. Clin. Med.*, **44**: 202.

Toll, A., Gallardo, F., Ferran, M., Gilaberte, M., Iglesias, M., Gimeno, J. L., Rondini, S. & Pujol, R. M. 2005. Aggressive multifocal Buruli ulcer with associated osteomyelitis in an HIV-positive patient. — *Clin. Exp. Derm.*, **30**: 649-651.

Tsukamura, M., Kaneda, K., Imaeda, T., Mikoshiba, H. 1989. A taxonomic study on a mycobacterium which caused a skin ulcer in a Japanese girl and resembled *Mycobacterium ulcerans* [in Japanese]. — *Kekkaku*, **64**: 691-697.

Uganda Buruli Group 1969. BCG vaccination against *Mycobacterium ulcerans* infection (Buruli ulcer). First results of a trial in Uganda. — *Lancet*, **1**: 111-115.

Uganda Buruli Group 1970. Clinical features and treatment of pre-ulcerative Buruli lesions (*Mycobacterium ulcerans* infection). Report II of the Uganda Buruli Group. — *Br. Med. J.*, **2**: 390-393.

Uganda Buruli Group 1971. Epidemiology of *Mycobacterium ulcerans* infection (Buruli ulcer) at Kinyara, Uganda. — *Trans. R. Soc. Trop. Med. Hyg.*, **65**: 763-775.

Van den Abbeele, K. G. 1962. Bacteriologic study of mycobacteria isolated in Congo and Rwanda-Burundi [in French]. — *Ann. Soc. Belg. Méd. Trop.*, **42**: 541-548.

Van der Werf, T. S., Van der Graaf, W. T., Groothuis, D. G. & Knell, A. J. 1989. *Mycobacterium ulcerans* infection in Ashanti region, Ghana. — *Trans. R. Soc. Trop. Med. Hyg.*, **83**: 410-413.

Van Nitsen, R. 1921. Treatment of tropical ulcer [in French]. — *Ann. Soc. Belg. Méd. Trop.*, **1**: 289-298.

Van Oye, E. & Ballion, M. 1950. Should we not take note of a new disease in Africa caused by acid-fast bacilli? A preliminary note [in French]. — *Ann. Soc. Belg. Méd. Trop.*, **30**: 619-627.

World Health Organization 2000. Buruli ulcer — *In*: Asiedu, K., Scherpbier, R. & Raviglione, M. (Eds.), *Mycobacterium ulcerans* infection. Geneva, The Organization.

World Health Organization 2001. Buruli ulcer. Diagnosis of *Mycobacterium ulcerans* disease. A manual for health care providers. — *In*: Portaels, F., Johnson, P. & Meyers, W. M. (Eds.), WHO/CDS/CPE/GBUI/2001.4. Geneva, The Organization, p. 92.

World Health Organization 2004. Buruli ulcer disease. *Mycobacterium ulcerans* infection: an overview of reported cases globally. — *Wkly Epidemiol. Rec.*, **79**: 193-200.

Ziefer, A., Connor, D. H. & Gibson, D. W. 1981. *Mycobacterium ulcerans*. Infection of two patients in Liberia. — *Int. J. Dermatol.*, **20**: 362-367.

Classe des Sciences techniques

Klasse voor Technische Wetenschappen

Bull. Séanc. Acad. R. Sci. Outre-Mer
Meded. Zitt. K. Acad. Overzeese Wet.
51 (2005-3) : 303-311

La statistique dans les pays en développement: regard et perspective *

par

Jean-Jacques Claustriaux **

Mots-cles. — Statistique; Biométrie; Agronomie; Outre-mer.

Resume. — Dans le cadre des pays en développement, notamment dans le domaine de la recherche agronomique, la présente communication tente d'apporter quelques réponses aux questions suivantes:
— La statistique est-elle spécifique?
— Quel est son rayonnement?
— Comment augmenter sa pénétration?

Trefwoorden. — Statistiek; Biometrie; Landbouwkunde; Overzee.

Samenvatting. — *Statistiek in ontwikkelingslanden: overzicht en vooruitzicht.* — Wat de ontwikkelingslanden betreft, en meer bepaald het landbouwkundig onderzoek, wordt in deze voordracht gepoogd een antwoord te geven op volgende vragen:
— Is statistiek specifiek?
— Wat is de uitstraling ervan?
— Hoe kan de impact ervan vergroot worden?

Keywords. — Statistics; Biometry; Agronomy; Overseas.

Summary. — *Statistics in Developing Countries: View and Tendency.* — In the context of developing countries, notably in the field of agronomical research, the author suggests some answers to the following questions:
— Is there a specificity in statistics?
— What is its influence?
— How to increase its field impact?

1. A propos de la statistique

Pour introduire ces quelques réflexions sur la statistique, particulièrement son impact dans les pays en développement, sujet choisi dans l'optique d'introduire

---

* Communication présentée à la séance de la Classe des Sciences techniques tenue le 25 novembre 2004. Texte reçu le 1er décembre 2004. Décision de publication prise le 24 novembre 2005.

** Unité de Statistique et Informatique, Faculté universitaire des Sciences agronomiques, av. de la Faculté 8, B-5030 Gembloux (Belgique).

un large échange de vues à la suite de l'exposé entre des personnalités scientifiques particulièrement instruites sur les conditions spécifiques de la recherche outre-mer, je ne peux que m'inspirer des propos cités par Meyer (2004) au début de son article sur «Les leçons de la nature», pour vous convaincre, si besoin est, que le statisticien n'est pas nécessairement un individu insensible aux charmes de celle-ci.

> Hostile ou accueillante, la nature cache aux hommes ses mystères, ne leur offrant à admirer que sa beauté. Mais les scientifiques, insatiables et fous du désir d'en violer les secrets, nous dévoilent sans cesse de nouvelles raisons d'être séduits.
>
> Autour de nous, il n'y a pas de plus simples, de plus parfaites leçons d'harmonie qu'une rose, le vol d'un oiseau ou le mouvement des vagues, mais c'est en **statisticien** que j'aimerais vous parler d'autres accords de la nature, aux charmes plus austères.

Comme le signale Dagnelie (1998a), le mot statistique est dérivé du substantif latin *status* (état) et il possède deux significations distinctes.

Utilisé le plus souvent au pluriel, le terme désigne tout ensemble cohérent de données, comme les statistiques de naissances ou les statistiques des productions agricoles. Employé au singulier, il concerne toutes les méthodes qui permettent de rassembler et d'analyser des données codées sous forme numérique.

Dans un cas comme dans l'autre, le quidam a tendance à retenir les aspects strictement mathématiques de la statistique, le calcul des probabilités en particulier, ce qui la rend souvent antipathique et difficile *a priori* (Nelder 1999). De plus, même pour certains scientifiques, elle est considérée comme une science inaccessible, difficile et nécessitant des prédispositions particulières pour sa maîtrise.

Pour ce qui nous concerne, rejoignant ainsi, notamment, les propos de Wegman (2000), si les aspects théoriques sont évidemment essentiels, nous préférons regarder la statistique sous un aspect beaucoup plus pratique, c'est-à-dire en la considérant davantage comme une discipline dont le commun dénominateur est la **donnée**, plutôt que la méthode, y associant aussi tout ce qui la lie à sa collecte, soit lors d'un échantillonnage, soit lors d'une expérimentation.

De cette manière, on mesure davantage, non seulement l'intérêt de la statistique, mais aussi son évolution (Droesbeke & Tassi 1990), en mettant également mieux en évidence son indissociable deuxième outil, lui beaucoup plus récent, à savoir l'informatique, le premier étant la mathématique.

Ainsi, de nouveaux sujets qui concernent la gestion de grandes quantités de données comme le *data mining*, l'analyse d'image, les modèles de reconnaissance, l'intelligence artificielle, la simulation aléatoire, etc., deviennent des traits fondamentaux de la discipline.

Signalons encore que le statisticien exerce une discipline assez singulière dans la mesure où il peut développer son savoir au service des autres scientifiques et qu'il n'est donc pas tenu de consacrer tout son temps à sa propre science pour mieux encore la mettre en évidence. C'est d'ailleurs en considérant le premier aspect que nous aborderons essentiellement la suite de l'exposé.

Un domaine de la recherche appliquée qui traite du vivant, ou de tout ce qui en est dérivé, et pour lequel la donnée a toujours fait l'objet d'attentions particulières est certainement l'agronomie. Dans ce contexte, la statistique est souvent appelée biométrie ou discipline visant à élaborer des modèles statistiques permettant une compréhension plus profonde des phénomènes biologiques.

Cette définition est cependant trop restrictive à mon point de vue car elle n'intègre pas suffisamment l'ensemble des règles pratiques qui conduisent à une action ou à une décision dans des conditions déterminées, c'est-à-dire qui lui associe ce que certains auteurs ont appelé la praximétrie (Martin & Henry 1960).

Enfin, vu la pénétration importante de la statistique pour traiter aujourd'hui des questions pharmaceutiques et médicales, le terme biométrie est de moins en moins utilisé; il est remplacé par l'expression biostatistique et même parfois par celle de biomathématique (Rasch *et al.* 1994).

2. La statistique outre-mer

Dans les pays en développement, le secteur économique que représente traditionnellement l'agriculture est toujours essentiel; dès lors, les activités de recherches associées sont indispensables et importantes. Plus récemment, à côté de tout ce qui concerne la production, la transformation et la valorisation des denrées alimentaires, la gestion de l'environnement, notamment celle des grands espaces boisés, et sa préservation sont devenues également une préoccupation majeure complémentaire.

Certes, que ce soit dans nos pays développés ou dans les pays en développement, la recherche en statistique, tout comme l'application des méthodes statistiques, sont analogues.

Toutefois, ce qui pour moi est très différent, ce sont, d'une part, les conditions dans lesquelles le statisticien travaille dans les pays d'outre-mer et, d'autre part, son isolement.

2.1. Les conditions de travail

Tout d'abord, dans ces pays, les données présentent davantage une variabilité élevée, souvent en raison des conditions du milieu particulièrement hétérogènes et mal contrôlées. A cette forte variabilité ou hétérogénéité vient s'ajouter l'existence fréquente d'accidents de parcours dans l'échantillonnage ou l'expérimentation.

Pour illustrer ces propos, considérons la forêt tunisienne qui a perdu un quart de sa superficie en quarante ans, soit plus de 250 000 hectares. Pour restaurer et reconstituer ce couvert végétal, des recherches à long terme sur une période de trente-six ans ont été entreprises dans quatre sites, notamment en matière de choix des provenances de pin d'Alep (*Pinus halepensis* Mill.). En résumé, la question essentielle qui se pose est de savoir comment la statistique peut contribuer à atteindre l'objectif fixé, compte tenu des conditions essentiellement pédologiques très variables et des taux élevés de mortalité des sujets?

Sans entrer dans tous les détails (Sghaier *et al.* 2004), des méthodes moins classiques, aux fondements théoriques mal connus, comme celles basées sur les modèles des plus proches voisins, peuvent, par approximations successives, contribuer largement à une meilleure prise en compte du contrôle local de l'hétérogénéité.

A titre d'exemple de modèle, celui repris ci-après identifie les voisins notés $X_{i,j}$, d'une provenance $Y_{l,c}$,située à la ligne l et à la colonne c d'un dispositif expérimental, et pour lequel il convient d'estimer le contrôle local de l'hétérogénéité $X_{l,c}$, b_1, b_2 et $\varepsilon_{l,c}$ étant respectivement les coefficients et le résidu aléatoire du modèle:

$$X_{l,c} = b_1\,(X_{l-1,c} + X_{l+1,c} + X_{l,c-1} + X_{l,c+1}\,) + b_2\,(\,X_{l-1,c-1} + X_{l+1,c+1} + X_{l+1,c-1} + X_{l-1,c+1}) + \varepsilon_{l,c}.$$

Grâce à ce type d'outil, il est donc possible d'extraire des observations, des quantités d'informations qui masquent la qualité recherchée d'une provenance en termes de hauteur, du diamètre, de la forme, du couvert végétal ou de la qualité du bois.

Ensuite, un second exemple va mettre en évidence une autre caractéristique des pays en développement, montrant à nouveau combien l'approche classique du traitement statistique des données est parfois bien difficile.

Cette fois, il se rapporte au domaine des enquêtes par échantillonnage dans des régions qui n'ont rien de commun avec les nôtres, dans la mesure où l'environnement économique est difficile et les informations préalables nécessaires à la mise en place d'enquêtes sont inexistantes, pauvres, erronées, obsolètes, inadéquates, volontairement biaisées, etc.; les moyens humains affectés à l'étude sont réduits ou peu qualifiés; les facteurs historiques ou politiques freinent la recherche d'informations objectives et, enfin, les délais impartis à l'enquête et à son analyse sont faibles, tout comme bien souvent les budgets.

Dans ce cas précis, l'objectif est d'évaluer la situation technico-économique des exploitations agricoles privées de deux régions de la République du Kirghizistan (Labe & Palm 1999), sachant qu'il n'est donc pas possible de mettre en place des méthodes statistiques classiques d'enquêtes en utilisant des bases de sondages pour ensuite calculer, notamment, des estimations et des marges d'erreur.

Dans une telle situation, il ne reste comme outil que les méthodes d'enquêtes dites informelles (Casley & Kumar 1988). L'objectif recherché est alors de comprendre davantage des systèmes (l'exploitation agricole, la structure familiale, l'organisation villageoise, etc.), en collectant des données qualitatives et en considérant l'enquêté, non pas comme une simple unité d'échantillonnage, «ignorante, bête et paresseuse» à observer, mais comme le principal partenaire avec lequel il convient de dialoguer pour obtenir la précieuse donnée. Le commun dénominateur pour la réussite de la mise en place de ces méthodes est donc de trouver des prétextes pour faciliter la discussion. Il est évident aussi que les questionnaires sont peu structurés et les observations sont des phrases, des schémas, des dessins, des comptes rendus de visites, etc.

Le travail d'analyse des données et l'interprétation des résultats ne peuvent évidemment se réaliser en principe que par des statisticiens qualifiés, ayant une connaissance suffisante du terrain et non par des «formulateurs» de principes purement théoriques.

J'ajouterai encore que dans certaines circonstances, la situation est telle que la seule méthode statistique disponible n'est hélas et tout simplement plus que l'intuition, sur base d'observations évidemment subjectives.

2.2. L'isolement

Au niveau individuel, la place occupée par le statisticien dans les pays en développement est tout à fait différente de celle rencontrée dans les pays développés.

Des études à long terme (Dagnelie 1998b) se référant aux membres de la Société internationale de Biométrie (*IBS*) ont montré que, quel que soit le secteur d'activité du statisticien, par rapport aux effectifs de la population, on pouvait considérer qu'en moyenne il y avait de l'ordre d'un statisticien par million d'habitants dans le monde, mais avec des disparités énormes entre les continents puisque, s'il y avait un statisticien pour 125 000 habitants en Amérique du Nord et au Canada, et un statisticien pour 500 000 habitants en Europe, en Australie, au Japon et en Nouvelle-Zélande, il n'y avait qu'un statisticien pour 5 000 000 habitants pour les autres pays du continent américain, l'Afrique, les autres pays d'Asie et l'Océanie, soit un rapport de un à quarante entre le Sud et le Nord. Par comparaison, la Société belge de Statistique compte de l'ordre d'un membre pour 100 000 habitants en Belgique.

A ces constatations, il faut cependant ajouter quelques éléments d'analyse, même si ces chiffres sont intéressants et qu'ils mettent parfaitement en évidence un déséquilibre permanent entre le Sud et le Nord au cours du temps.

En effet, les données ne sont que le reflet de la répartition géographique des membres d'une seule société scientifique internationale et elles ne précisent pas ce qu'est un membre: statisticien isolé ou non, enseignant de la statistique sans pratique de celle-ci, statisticien théoricien ou praticien, etc. Par ailleurs, rapporter les résultats à la population est certes nécessaire, mais il conviendrait d'évaluer également la présence relative du statisticien par rapport aux autres scientifiques, chiffres beaucoup plus difficiles à obtenir.

Néanmoins, cette plus faible présence de statisticiens dans les pays du Sud est hélas aussi accentuée par le fait que nous avons pu constater que la statistique et le statisticien sont relativement «ignorés» dans l'enseignement et la recherche. Dès lors, le chercheur en sciences biologiques ne peut se rendre compte, ni résoudre des questions essentielles, qui se posent à lui en termes de planification expérimentale et d'interprétation des résultats. De plus, trop souvent, bien informé de la théorie, mais maîtrisant très peu des notions biologiques fondamentales, le mathématicien prend la place du biométricien, sans pour autant résoudre les questions plus appliquées. Aussi, les articles scientifiques proposés par les chercheurs de ces pays sont souvent refusés par les éditeurs du Nord faute d'une planification expérimentale adéquate ou d'une inadéquation entre les objectifs de la recherche et les méthodes statistiques utilisées (NELDER 1999).

Dans cet isolement, les statisticiens du Sud ont aussi leur part de responsabilité pour une question de mentalité, de perspectives professionnelles, etc.

Cependant, reconnaissons que la situation d'isolement relatif du statisticien outre-mer s'est améliorée, grâce, notamment, à l'arrivée massive des ordinateurs, des logiciels libres ou non et de l'accès au réseau internet, facilitant ainsi la réalisation des calculs et la mise à disposition de nouvelles méthodologies.

3. Quelques suggestions

Face à ce constat, spécificité des conditions de travail et présence moindre du statisticien dans les pays du Sud, que faire pour favoriser une amélioration de la situation?

Si réduire la variabilité n'est évidemment pas possible, il ne reste qu'à proposer des actions au niveau des hommes eux-mêmes.

Mais, avant d'apporter des éléments de réponse, ne faut-il pas s'interroger sur l'opportunité d'accroître la présence du statisticien outre-mer?

Par une simple phrase, Wilson (*in* NELDER 1999) répond à la question: «the presence of regulatory statisticians in the pharmaceutical field has surely been the major reason that the industry has become such a major employer of statisticians».

Le rôle joué par le statisticien en matière de recherche-développement dans ce secteur, certes particulier, a donc certainement un impact économique positif, tout comme pour l'entreprise publique ou privée, si la sécurité coûte, cela coûte davantage de ne pas s'en préoccuper. Pourquoi en serait-il autrement dans d'autres secteurs économiques, dont celui du développement?

En conséquence, quelles pourraient être les actions à entreprendre pour encourager une meilleure pénétration de la statistique?

Dans le contexte des décideurs publics ou privés, il est évident que toute institution universitaire ou de recherche scientifique ne devrait porter ces qualificatifs que si la présence de statisticiens expérimentés est effective, si besoin en association.

Par ailleurs, ces décideurs devraient aussi mieux se rendre compte que les bailleurs de fonds se préoccupent de cet indicateur puisque la qualité des résultats des travaux est souvent jugée par des experts statisticiens *a posteriori*, mettant ainsi éventuellement en cause la crédibilité de l'institution de recherche elle-même.

Mettre en valeur nos collègues statisticiens étrangers dans nos enseignements, même de premier ou de deuxième cycle, au titre de professeur visiteur, est une action qui devrait aussi être mieux soutenue, par exemple par la création de Chaires du Sud ou mieux encore de Chaires d'Excellence.

En effet, il ne faut pas cacher que des problèmes de carrière professionnelle se posent pour nos collègues étrangers, surtout si celle-ci est davantage valorisée par des publications plutôt que par des conseils judicieux à d'autres collègues.

Par ailleurs, puisque le statisticien est souvent seul, isolé dans son institution et qu'il agit parfois sur de vastes territoires, toute action qui favorisera la communication avec le monde extérieur, celui du Nord en particulier, pour lutter contre l'isolement scientifique rapide en statistique et encore plus en informatique doit être soutenue (séjours d'études, de recyclages, établissement de réseaux thématiques de statisticiens, via internet, etc.).

Un étudiant est très rarement enclin à étudier la statistique ou à se spécialiser en la matière. Il faut donc créer des filières d'enseignement spécifiques, davantage orientées vers le traitement statistique et informatique des données, et implémenter des incitants ou des encouragements à ces formations, tels que des bourses de formation, des prix pour récompenser des travaux réalisés dans le secteur, des subsides pour aider les jeunes statisticiens d'outre-mer à communiquer dans les colloques internationaux, pour autant que les organisateurs de ces derniers restent ouverts à des problématiques plus traditionnelles ou plus pragmatiques, ce qui est hélas de moins en moins le cas.

Si l'éthique en expérimentation humaine est une préoccupation certes essentielle et si elle concerne aujourd'hui toute la recherche animale, ne devrait-elle pas aussi concerner le secteur du végétal, si ce n'est pas pour la défense de l'organisme en tant que tel, tout au moins pour une question liée au coût de la recherche?

Dans ce cadre, tout chercheur pourrait rapidement se rendre compte que le statisticien est loin d'être un gêneur, mais qu'il est davantage un conseiller ou un allié pour, par exemple, peser sur le nombre de sujets à observer, le statisticien ne devant plus être ainsi cantonné au simple rôle d'analyseur des données.

En résumé, sans l'aval du statisticien, pas de recherche et donc plus d'institution de recherche, au Nord comme au Sud! Certaines entreprises ont parfaitement adopté ce principe depuis longtemps.

Le bon usage de la statistique doit encore être encouragé par la rédaction et la diffusion auprès des auteurs d'articles et des éditeurs de revues non statistiques de guides des bonnes pratiques statistiques en matière d'expérimentation, d'échantillonnage et de publication de résultats. En particulier, par exemple, ces derniers ne devraient plus être considérés comme ayant une caution statistique suffisante par la simple présence dans les articles d'astérisques assimilant ainsi automatiquement le rejet d'une hypothèse à un progrès scientifique.

A l'heure de l'image et de la communication, si les mots ont leur importance pour une meilleure perception d'un domaine au Nord comme au Sud, ne faut-il pas donner à la statistique la place qui lui revient en identifiant un maximum de structures organisationnelles par les termes «science statistique» dans l'appellation des instituts, des départements ou des unités en lieu et place du simple mot «statistique»?

Dans cet isolement, les sociétés scientifiques, c'est-à-dire les statisticiens associés, ont aussi à apporter leur contribution comme nous l'avons déjà évoqué. Ne devraient-elles pas davantage considérer également comme dignes d'intérêt des publications à caractère moins théorique et organiser systématiquement, durant les réunions scientifiques, des séances plus appliquées sur des thèmes mettant en valeur le bon usage de la pratique statistique outre-mer, certes en prévoyant également des modalités plus avantageuses de participation à des congrès pour des ressortissants du Tiers-Monde?

Nous-mêmes, individuellement, statisticiens des pays dits développés, ne devrions-nous pas consacrer davantage de temps à ces pays en développement:

— Par des formations locales pour les chercheurs du Sud ou la participation à des séminaires régionaux, éventuellement à distance;
— Grâce aux moyens actuels et rapides de communications en initiant des centres-relais de consultations statistiques aussi pour les chercheurs du Sud, de manière à mieux définir les objectifs de leurs travaux et à mieux mettre en valeur les résultats obtenus;
— En influençant nos autorités, au sein de nos institutions, à mieux valoriser nos jeunes collègues qui consacrent une partie de leur temps de recherche en faveur des pays en développement pour leurs promotions académiques;
— Etc.

4. En guise de conclusion

La statistique est certainement un domaine de la science qui a discrètement contribué au développement socio-économique des pays du Sud, souvent sans nécessairement faire appel à des méthodologies sophistiquées. Mais, son taux de pénétration est moins important qu'au Nord et sa progression est lente, malgré plusieurs signaux d'alarme déjà anciens (Dagnelie 1984, Otoul 1994), alors que d'aucuns affirment que la maîtrise des nouveaux savoirs et la culture technologique sont devenues les seuls garants du développement durable du Sud.

Plus encore dans ces régions du monde aux conditions de milieux spécifiques, il nous semble que la qualité des recherches entreprises va de concert avec une présence plus effective de la statistique sur le terrain et qu'il faut l'encourager.

Sans cela, les travaux de recherches et les publications qui en découleront n'auront généralement plus de véritable portée et ne contribueront plus à un véritable développement, sauf si tout chercheur fait, tel Monsieur Jourdain, de la statistique sans le savoir…

BIBLIOGRAPHIE

Casley, D. J. & Kumar, K. 1988. The collection analysis, and use of monitoring and evaluation data. — Baltimore, Johns Hopkins University Press, 174 pp.

Dagnelie, P. 1984. La situation de la biométrie dans les pays du tiers monde. — *Biom. Praxim*, **24**: 3-21.

Dagnelie, P. 1998a. Statistique théorique et appliquée (tome 1: Statistique descriptive et bases de l'inférence statistique). — Bruxelles, De Boeck & Larcier, 508 pp.

Dagnelie, P. 1998b. A quantitative vision of biometry in developing countries. — *Biom. Bull.*, **15**: 6-9.

Droesbeke, J.-J. & Tassi, P. 1990. Histoire de la statistique. — Paris, Presses Universitaires de France, 128 pp.

Labe, V. & Palm, R. 1999. Statistique, empirique, informelle: quelle enquête pour la collecte d'informations sur les exploitations agricoles? — *Cahiers Agricultures*, **8**: 397-404.

Martin, L. & Henry, J. 1960. Editorial. — *Biom. Praxim*, **1**: 2-4.

Meyer, D. 2004. Les leçons de la nature. — *Le Monde*, **18585**: 20.

Nelder, J. A. 1999. Statistics for the Millennium. — *The Statistician*, **48**: 257-269.

Otoul, C. 1994. La statistique et la recherche agronomique dans les pays du tiers-monde: son passé et les tendances nouvelles. — *Biom. Praxim*, **34**: 147-161.

Rasch, D., Tiku, M. L. & Sumpf, D. 1994. Elsevier's dictionary of biometry. — Amsterdam, Elsevier, 887 pp.

Sghaier, T., Claustriaux, J.-J. & Beji, M. A. 2004. Intérêt des modèles des plus proches voisins pour le contrôle de l'hétérogénéité spatiale: application à un essai de provenances de Pin d'Alep (Pinus halpensis Mill.) en Tunisie. — *Revue de l'INAT*, **19** (2): 5-22.

Wegman, E. J. 2000. On the eve of the 21st century: statistical science at a crossroads. — *Comp. Stat. Data Anal.*, **32**: 239-243.

Bull. Séanc. Acad. R. Sci. Outre-Mer
Meded. Zitt. K. Acad. Overzeese Wet.
51 (2005-3) : 313-316

Addendum* to the paper "On the Amount of Rain Fallen in Macau, China, in the Year 1780"

(*Bull. Séanc. Acad. R. Sci. Outre-Mer*, **49** (2003-4): 497-506)

by

Gaston DEMAREE**, ZHANG DE'ER*** & Øyvind NORDLI****

KEYWORDS. — Rainfall; Typhoon; Macau; Swedish East India Company.
SUMMARY. — Chinese historical climate-related documentary information is presented to explain why the dryness/wetness index for the year 1780 for the Guangdong area was stated as wet. That fact presented a contradiction with the observations of an anonymous observer of the Swedish East India Company at Macau, China, in the year 1780. It is shown how both climate information sources can be complementary.

TREFWOORDEN. — Neerslag; Tyfoon; Macau; Zweedse Oost-Indische Compagnie.
SAMENVATTING. — Chinese historische klimaatinformatie wordt voorgelegd om aan te tonen waarom de droogte/natheid index voor het jaar 1780 voor de Guangdong provincie als nat werd gedefinieerd. Dit feit stelde een tegenstelling voor met de waarnemingen van een anonieme waarnemer van de Zweedse Oost-Indische Compagnie in Macau, China, in het jaar 1780. Het toont de complementariteit van beide databronnen aan.

MOTS-CLES. — Précipitations; Typhon; Macao; Compagnie Suédoise des Indes.
RESUME. — Des informations historiques chinoises relatives au climat sont présentées dans le but d'expliquer le pourquoi de la caractérisation «pluvieuse» donnée à l'indice pluviométrique pour l'année 1780 dans la province de Guangdong. Ce fait était en contradiction avec les observations d'un observateur anonyme suédois travaillant, en 1780, à Macao, Chine, pour la Compagnie Suédoise des Indes. Nous montrons ici comment les deux sources d'information climatique peuvent être complémentaires.

*
* *

A manuscript in Swedish language comprising instrumental rainfall data in Macau, China, for the year 1780, has been studied in the above-mentioned paper.

* Received on 12 April, 2005.
** Royal Meteorological Institute of Belgium, Ringlaan 3, B-1180 Brussels (Belgium).
*** National Climate Centre, 100081 Beijing (China).
**** Norwegian Meteorological Institute, Box 43, Blindern, N-0313 Oslo 3 (Norway).

The manuscript seems to be, among the extant manuscripts of the Swedish East India Company (SEC), the only one dealing with instrumental meteorological observations on Chinese territory. The authors of the paper have compared these observations with the present-day normal values of rainfall in Macau.

It was however questioned in the ensuing discussion (see p. 506) that a contradiction was noticed between the accompanying weather descriptions in the manuscript, the rainfall statistics at Macau and the yearly dryness/wetness index for the year 1780 for the Guangdong Province elaborated by the Chinese Academy of Meteorological Science (1982, p. 161).

In the margin of his instrumental rainfall observations, the Swedish anonymous observer noted that "The weather this spring was unusually dry and beautiful. April as it is here usually quite wet and stormy, as the periodic winds then shift, was now very nice. The seamen foresaw from this a very stormy summer, but this didn't happen. At the end of September was here one storm, a typhoon, but it was among the weaker ones". The Swedish observer continues: "Also the summer, as a whole, was beautiful, not among the hottest, but dry; thunder was seldom observed. Until the beginning of September, northerly winds blew over the country, but further to the sea southwest, from this the great rain is easy to explain". Similarly, the comparison of the rainfall statistics of the year 1780 with the present-day ones (even taking into account a slight underestimation due to ancient non-standardized procedures) suggests a dry year.

The key lies in the fact that the Swedish observer ended his observations abruptly on September 12th, 1780, presumably leaving for Canton. Heavy rainfall was observed by the Swedish observer on August 2nd and 4th, on September 9th and 10th, the last values being responsible for an incomplete monthly value above the 1971-2000 normal value for a whole month. The Swedish observer further mentions heavy rain in September and a weak typhoon at the end of September.

On the contrary, the yearly dryness/wetness index for the year 1780 for the province was defined as wet. Prof. Zhang De'er, National Climate Centre at Beijing, kindly provided the historical climate-related documentary information, enabling us to better understand both views. From the Chinese historical documentary records (Zhang De'er, Compendium, p. 2573), the following historical climatic information has been included for the Guangdong area. Prof. Zhang De'er converted the lunar calendar dates into Gregorian calendar dates; the Chinese data source is mentioned between brackets.

- Wuhua: heavy rain with gale and hail on March 3 (in Gregorian calendar: April 7), houses and trees damaged (Chronicle of Changle County, during Emperor Daoguang, Vol. 7).
- Chaoyang (23.262 ºN, 116.593 ºE): rainstorms, one in June (in Gregorian calendar: July 3 – 30) and one in July (in Gregorian calendar: July 31 – August 29) doing damage to the street on the south side of the Sub-Eastern

Gate, to the street by the Fortress North No. 1 and to the city wall nearby the Fortress North No. 3. In these events the city wall collapsed about 13 meters and 10 meters, respectively, in the SW and NW, as well as ravaged street defence structures, in total at 7 places in the district of Haimen (Chronicle of Chaoyang County during Emperor Jiaqing of Qing, Vol. 3).

— Chaozhou (23.083 ºN, 114.417 ºE): typhoon and flood damage in August (in Gregorian calendar: August 30 – September 27) (Chronicle of Haiyang County during Emperor Guangxu of Qing Dynasty, Vol. 25).

— Chaoyang (23.262 ºN, 116.593 ºE): typhoon and flooding on August 27 (in Gregorian calendar: September 25)(*ibid.*, Vol.12).

— Chenghai (23.425 ºN, 117.017 ºE): typhoon in August (in Gregorian calendar August 30 – September 27) (Chronicle of Chenghai County, during Emperor Jiaqing, Vol. 5).

— Huiyang (23.083 ºN, 114.417 ºE): flooding in September (in Gregorian calendar: September 28 - October 27) and no harvest in low land (Chronicle of Guishan County during Emperor Qianlong of Qing Dynasty, Vol. 2).

From these Chinese historical documentary climate-related information it is noted that a typhoon struck the Guangdong area on September 25, 1780, causing flooding in Chaoyang. Based upon the rainstorms accompanied by damage in July and August, and on the typhoon in September, the Chinese scientists concluded the year 1780 was a wet year.

Conclusion

Besides the fact that the instrumental observations of the Swedish observer did end on September 12th, 1780, the accompanying notes mention a wet September together with the occurrence of a weak typhoon at the end of September. However, the Swedish observer states in Macau the year 1780 as dry, while Chinese scientists basing themselves on historical data from the whole Guangdong province for the rainy season, May through September for South China, graded the year 1780 as wet. This conclusion may still be indicative of a difference in perception or in the methodology in defining a yearly index for a province. It shows that the Chinese and the westerner's climate-related information is complementary, leading to fruitful comparative results, most useful in climate reconstruction.

ACKNOWLEDGEMENTS

The authors are most grateful to Anne Wiktorsson, archivist, Center for History of Sciences, Royal Swedish Academy of Sciences at Stockholm for having provided a photocopy of the manuscript to the lead author.

REFERENCES

Anonymous 1780. Dag Bok över huru mycket Rägn-Vatten, fallet i Macao på en Svensk quadrat Fot, ifrån Martii månads början til och med den 12 September år 1780. — Stockholm, Royal Swedish Academy of Sciences, Center for History of Science, 3 pp.

Chinese Academy of Meteorological Science 1982. Yearly charts of dryness/wetness in China for the last 500-year period. — Beijing, Cartographic Publishing House, 332 pp. (in Chinese).

DEMAREE, G. & NORDLI, Ø. 2004. On the Amount of Rain Fallen in Macau, China, in the year 1780. — *Bulletin des Séances, Académie Royale des Sciences d'Outre-Mer / Mededelingen der Zittingen, Koninklijke Academie voor Overzeese Wetenschappen*, **49** (4): 499-506.

ZHANG DE'ER 2004. A Compendium of Chinese Meteorological Records of the Last 3,000 Years. — Nanjing, China, Jiangsu Education Publishing House, 4 vol., 3666 pp. (in Chinese with English introduction).

Bull. Séanc. Acad. R. Sci. Outre-Mer
Meded. Zitt. K. Acad. Overzeese Wet.
51 (2005-3) : 317-344

Environmental and Palaeoclimatic Significance of the Magnetic Signal in Lœss-Palaeosol Sequences*

by

Jozef Hus**

Keywords. — China; Loess; Magnetic Susceptibility; Palaeomagnetism; Palaeoclimate.

Summary. — Loess-palaeosol sequences are amongst the most important natural archives providing past environmental and climatic information on the continents. In the Loess Plateau of China, the alternation of loess units and interbedded palaeosols indicates climate changes between glacial and interglacial monsoon regimes. The magnetic content of these sediments reflects ancient geomagnetic field behaviour and in particular of field reversals that may provide time constraints for climate proxy records. However, geomagnetic field reversals are often recorded as multiple reversals, suggesting a complex field recording history. The magnetic content informs us also about environmental changes and in particular palaeoclimatic changes. After it was recognized that palaeosols in China have a high magnetic susceptibility, related to soil formation processes, the latter has been considered as a climate proxy. It has been successfully used to trace climatic changes on different timescales, and measurements of modern soils on the Chinese Loess Plateau point to a relation with precipitation and temperature. However, the climate response of this rock magnetic parameter is still not completely understood. Different models have been proposed for the magnetic remanence acquisition mechanism in loess and soils and for the enhanced magnetic properties of soils.

Trefwoorden. — China; Löss; Magnetische Susceptibiliteit; Paleoklimaat; Paleomagnetisme.

Samenvatting. — *Betekenis van het magnetisch signaal in löss-paleobodemsequenties in verband met de omgeving en het paleoklimaat.* — Löss-bodemsequenties behoren tot de voornaamste natuurlijke archieven met informatie over de paleo-omgeving en het klimaat op de continenten. In het Loess Plateau van China wijst de afwisseling van löss-eenheden en bodems op klimaatsveranderingen van glaciale en interglaciale moesson-regimes. De magnetische inhoud van deze sedimenten weerspiegelt veranderingen van het geomagnetisch veld in het verleden en in het bijzonder van de veldomkeringen, die beperkingen opleveren voor registraties van klimaatindicatoren. Meestal werden de geomagnetische polariteitsveranderingen in loess opgetekend als veelvuldige omkeringen, die

* Paper presented at the meeting of the Section of Technical Sciences held on 24 November, 2005. Text received on 19 January, 2006.

** Head of Department, Centre de Physique du Globe de l'IRM, B-5670 Dourbes (Belgium).

wijzen op een complexe geschiedenis van de veldregistratie. De magnetische inhoud informeert ons eveneens over veranderingen van de omgeving en in het bijzonder van het paleoklimaat. Na de ontdekking dat paleobodems in China een hoge magnetische susceptibiliteit vertonen, verbonden met de bodemontwikkeling, werd deze opgevat als klimaatindicator. Hij werd met succes toegepast om klimaatsveranderingen op te sporen op verschillende tijdschalen, en metingen van de moderne bodem wijzen op een verband met temperatuur en neerslag. Nochtans is de klimaatrespons van deze gesteentemagnetische parameter niet goed gekend. Verschillende modellen werden voorgesteld voor de remanente magnetisatie in löss en bodems en voor de sterk uitgesproken magnetische eigenschappen van bodems.

MOTS-CLES. — Chine; Lœss; Paléomagnétisme; Paléoclimat; Susceptibilité magnétique.

RESUME. — *Signification environnementale et paléoclimatique du signal magnétique dans les séquences lœss-paléosols.* — Les séquences lœss-paléosols figurent parmi les plus importantes archives naturelles fournissant de l'information quant à l'environnement et le climat du passé sur les continents. Dans le Plateau des Loess en Chine, l'alternance des unités de lœss et des paléosols intercalés, indique les changements du climat des régimes glaciaires et interglaciaires des moussons. Le contenu magnétique de ces sédiments reflète les variations du champ géomagnétique dans le passé et en particulier les inversions du champ qui fournissent des limites pour les enregistrements des indicateurs climatiques. Le plus souvent, les changements de polarités géomagnétiques sont enregistrés dans les lœss comme des inversions multiples, indiquant une histoire complexe de l'enregistrement du champ. Le contenu magnétique nous informe également sur les variations de l'environnement et en particulier du paléoclimat. Peu après la découverte que les paléosols du Plateau des Lœss en Chine ont développé une susceptibilité magnétique élevée, cette dernière a été considérée comme un indicateur du climat. Il a été appliqué avec succès pour détecter des variations du climat à différentes échelles de temps, et des mesures du sol actuel ont montré des corrélations avec la température et la pluviosité. Toutefois, la réponse de ce paramètre magnétique au climat n'est pas encore bien connue. Différents modèles ont été proposés pour le mécanisme d'acquisition de l'aimantation rémanente par les lœss et les sols, et pour le renforcement des propriétés magnétiques des sols.

1. Introduction

Magnetic particles are very sensitive to physical and chemical processes occurring during the transfer of material in the lithosphere, hydrosphere and atmosphere. Therefore, the magnetic content of sedimentary rocks, including aeolian deposits, contains information about these processes and hence about environmental changes and in particular palaeoclimatic changes. During or after deposition, magnetic particles may become aligned or magnetised along the geomagnetic field and consequently the remanent magnetisation of a sediment acts as a memory of ancient geomagnetic field behaviour.

Palaeomagnetic investigations of sediments have proven to be very useful for palaeoenvironmental and in particular for palaeoclimate reconstructions, mainly for two reasons: they provide time markers, and some rock magnetic properties may be considered as climate proxies. The remanent magnetisation yields time markers, often based on recorded geomagnetic field reversals, which are the basis of polarity magnetostratigraphy and used to tie climate proxy records in sediments to insolation changes, ice-volume changes, or to correlate them with the earth orbital changes in function of time, called tuning of proxy climate records. Some rock magnetic parameters, such as magnetic susceptibility, a property reflecting the magnetic content of sediments, are considered to be proxies of the climate.

In the following an overview will be given of the application of palaeomagnetism and rock magnetism as tools for palaeoenvironmental and palaeoclimate reconstructions in the loess-palaeosol sequence of the Chinese Loess Plateau, with emphasis on the palaeoclimatic significance of magnetic susceptibility, as well as some perspectives for further research.

2. Loess and Loess-Palaeosol Deposits

The term Loess is derived from the German word *Löss*, meaning loose, and was for the first time used by German geologists to designate loose, non-stratified, silty deposits along the Rhine near Heidelberg (SMALLEY *et al.* 2001). In the Chinese language it is called *Huangtu*, meaning yellow earth. Already in 1882, von Richthoven recognized the aeolian origin of the loess blanket in China. Indeed, loess deposits are clastic deposits, commonly non-stratified and non-consolidated, occurring as wind-laid sheets, yellowish in colour and consisting mainly of silt-size particles in the range of 20-50 μm. The main loess building minerals are quartz, feldspar and carbonates.

Many theories had been proposed for the loess formation, but the most commonly accepted explanation for their origin in Europe is that the silt-sized particles were produced by sub-glacial grinding, followed by aeolian transportation and deposition (SMALLEY 1966). In cold and dry areas, the loess constituents may also result from frost action and salt weathering (DERBYSHIRE 1983). Also basin outwash may supply the particles that are transported by wind, when the water level drops during cold periods.

Loess covers about 10 % of the total land surface, mainly in the temperate climate belt, in Alaska, America, Argentina, Europe, Asia and New Zealand, and consequently it is one of the principal continental sediments (CATT 1986, PYE 1987) (fig. 1).

Loess deposits consist of an alternation of loess units of yellowish colour, deposited in cold and arid conditions, with interbedded soils that developed when the climate was milder. The most extensive and thickest loess deposits

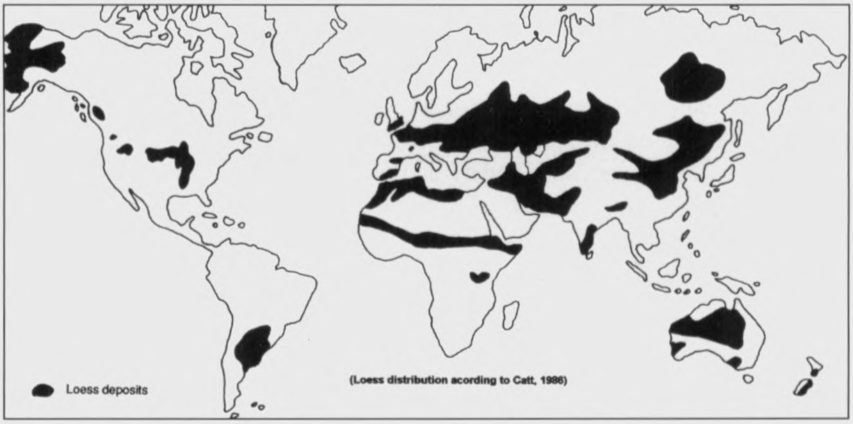


Fig. 1. — Loess covers about 10 % of the total land surface of the earth, mainly in the temperate climate belt, in Alaska, America, Argentina, Europe, Asia and New Zealand, and consequently it is one of the principal continental sediments (after Catt 1986).

occur in the People's Republic of China, covering an area of about 440,000 km^2 and commonly exceeding a thickness of 100 m and even more than 300 m in some places (fig. 2). In China, the soil and loess units have been labelled starting from the top: respectively S0, S1, S2,... and L1, L2, L3,... as is shown in figure 3a for the upper part of the loess-palaeosol sequence in Huangling, not far from Luochuan, and in figure 3b for the impressive lower part of the sequence in Jiachun near Baoji.

3. Historical Overview of Loess Magnetic Investigations in the People's Republic of China

In a seminal paper published in *Nature* in 1982, Heller and Liu demonstrated that geomagnetic field reversals were recorded in a core drilled in the Central Loess Plateau of China in Luochuan (Shaanxi province) (figs. 2, 4). This proved in the first place that a stable remanent magnetisation component was present in the Chinese loess cover, reflecting ancient field behaviour. Based on the Matuyama/Brunhes reversal Boundary (MBB), which was located in soil S8, identification of the Jaramillo and Olduvai subchronozones and the Gauss/Matuyama reversal found in the top of the underlying Poteh clay, the authors estimated that loess started to accumulate on the Loess Plateau in China at least 2.5 myr ago (figs. 4, 7).

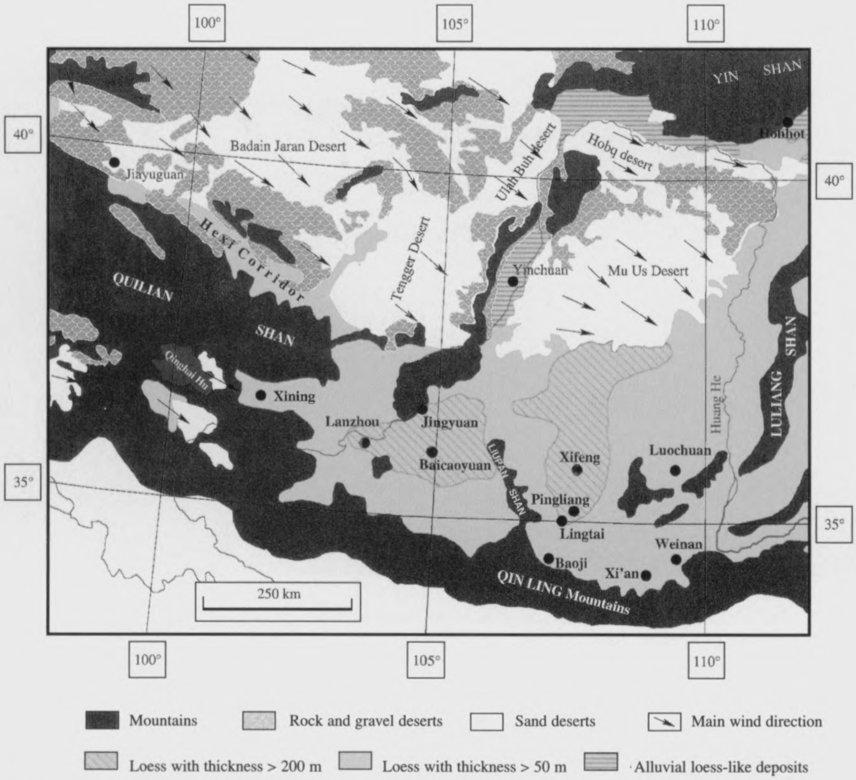


Fig. 2. — Loess distribution and loess source areas of the Chinese Loess Plateau. Arrows indicate main wind directions caused by a stable anticyclone centred over southern Siberia and Mongolia from December until March (redrawn from WANG & SONG 1983).

They also noticed that bulk low-field magnetic susceptibility was about twice as high in the palaeosols compared to the less weathered loess, and suggested that this rock magnetic parameter may reflect climatic changes (fig. 4). The same authors drew the attention to a close resemblance of the magnetic susceptibility signature of the Chinese loess-palaeosol sequence with oxygen isotope ($\delta^{18}O/\delta^{16}O$) records from $CaCO_3$ tests in deep-sea sediments (HELLER & LIU 1984).

The magnetostratigraphic dating by Heller and Liu lead to a refinement of the loess stratigraphy in China and their observations triggered interest in magneto-climatology of loess-palaeosol sequences in general and especially across the Chinese Loess Plateau (KUKLA & AN 1989, RUTTER *et al.* 1991, HELLER & EVANS 1995, THOMPSON & MAHER 1995).

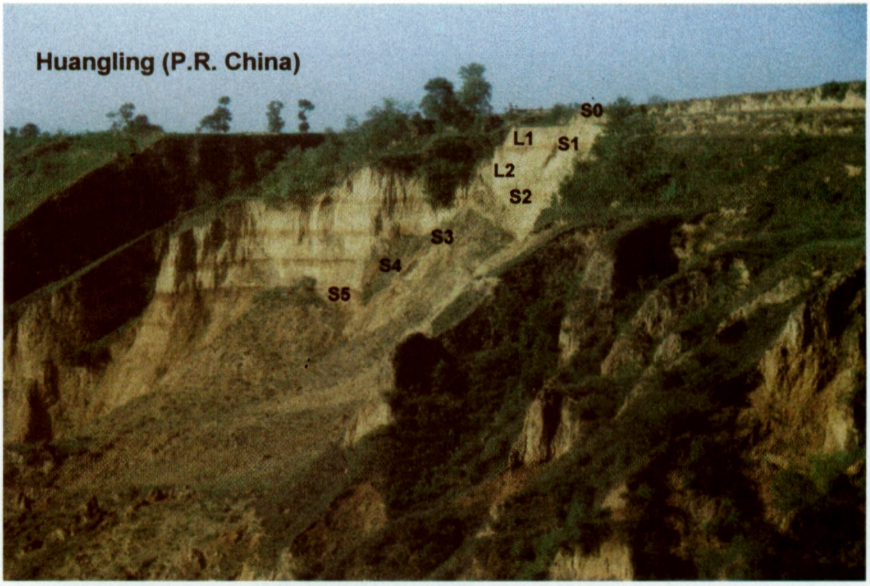


Fig. 3a. — Loess-palaeosol sequence in Huangling near the type locality of the Chinese loess stratigraphy in Luochuan. Soil and loess units have been labelled starting from the top: respectively S0, S1, S2,... and L1, L2, L3,... (photograph taken by the author).

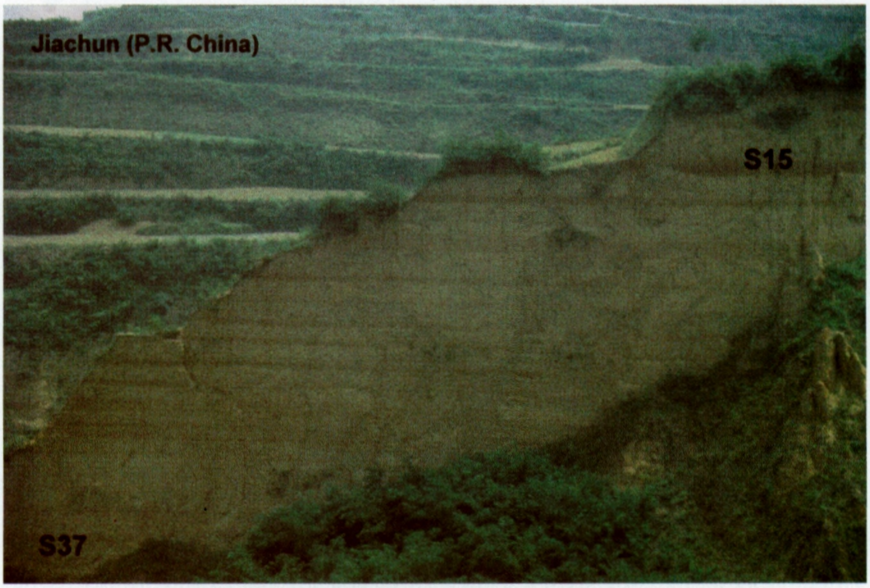


Fig. 3b. — Lower part of the the loess-palaeosol sequence in Jiacun near Baoji (photograph taken by the author).

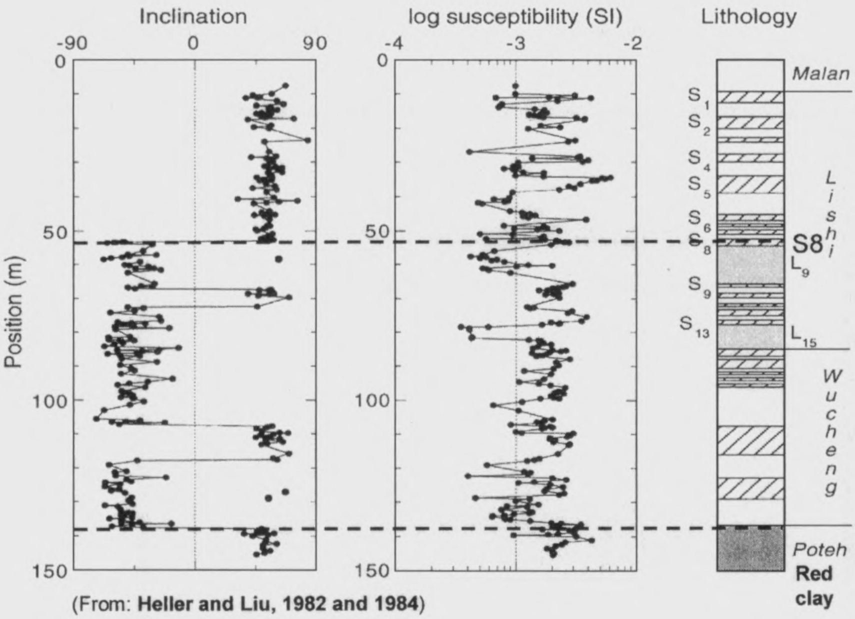


Fig. 4. — Magnetic inclination and magnetic susceptibility logs of the borehole at Luochuan after Heller & Liu 1982, 1984. The main lithostratigraphic units are named Malan, Lishi and Wusheng loess and Poteh clay according to Liu & Chang 1964. In the lithostratigraphic column, loess layers (L) are in white or stippled and palaeosol units (S) are hatched. Positions of the Matuyama-Brunhes (MB) and Gauss-Matuyama (GM) geomagnetic polarity transitions are indicated by horizontal dotted lines.

Magnetic Susceptibility (MS) was in the first place used to correlate loess sections and proved to be a very powerful tool to detect incipient soils that escaped observation in the field (Han *et al.* 1991). A similar MS signature, as in the type locality of the Chinese loess stratigraphy in Luochuan, was found in the Xiadong section in Jixian (Xhanxi province), east of the Huanghe River, at about 120 km east from Luochuan (Hus & Han 1991, 1992). Both MS profiles were compared with the marine oxygen isotope profile from a core from site 677 of the Ocean Drilling Program (ODP677) in the equatorial Pacific Ocean and SPECMAP 84 (fig. 5).

Striking was the similarity of the MS signature and the one-to-one relationship between the loess and palaeosol units of the Chinese Loess Plateau with those in loess sections in Tadjikistan. This remarkable correspondence is shown in figure 6 for the Huangling section near Luochuan and the Tadjijar section in Tadjikistan, from the present until the lower boundary of the Jaramillo subchron. The MS record of the former was stretched until the MBB recorded was at the

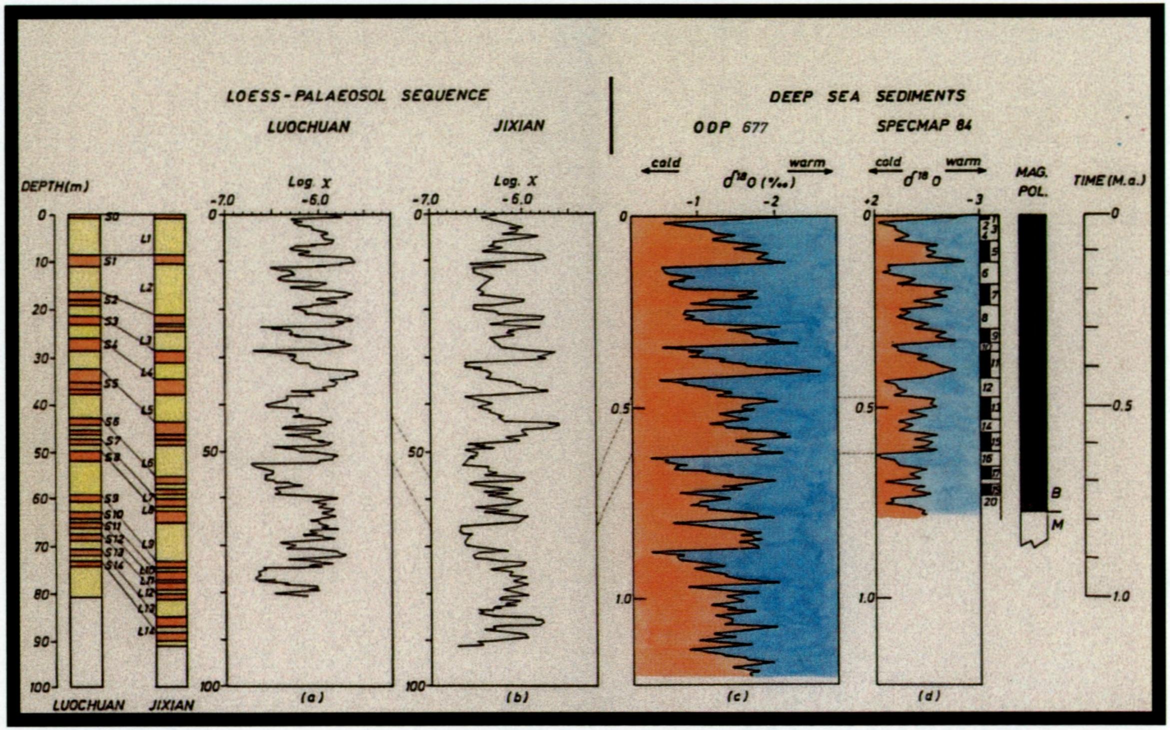


Fig. 5. — Comparison of the MS signature of the loess-palaeosol sequence in the type locality of the Chinese loess stratigraphy in Luochuan (Xhaanxi province) with the Xiadong section in Jixian (Xhanxi province), near the Huanghe river, at about 120 km to the East from Luochuan (see also HUS & HAN 1992). Both MS profiles (a) and (b) show great similarity with the marine oxygen isotope profile from a core from site 677 of the Ocean Drilling Program (ODP677) in the equatorial Pacific Ocean (c) and SPECMAP 84 (d).

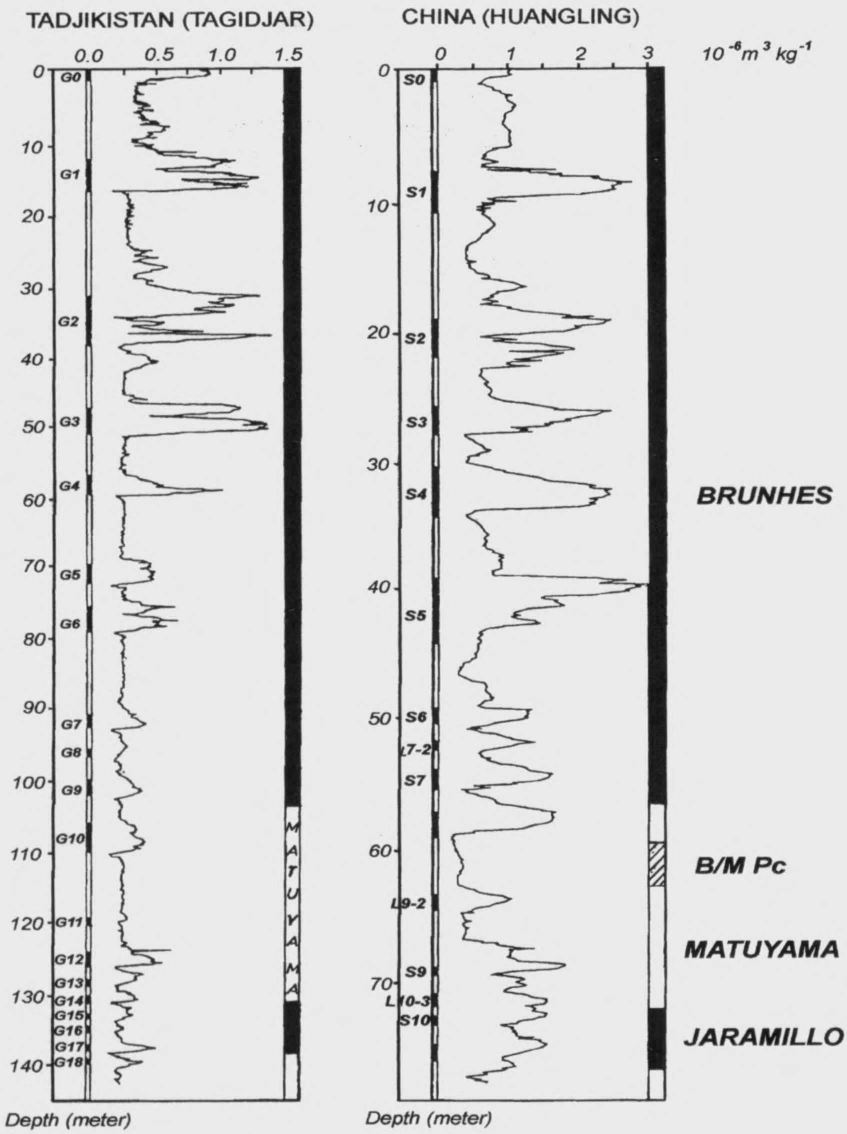


Fig. 6. — Striking correspondence of the Magnetic Susceptibility (MS) signatures of the loess-palaeosol sequence in the Chinese Loess Plateau in the Huangling section near Luochuan and the Tadjijar section in Tadjikistan, after stretching the MS record of the former until the MB boundary recorded was at the same level as in the latter (Hus and Haesaerts). Notice that MS attains lower values and that the accumulation rate is much higher in the Tadjidjar section compared to the Huangling section (B/M Pc: Brunhes/Matuyama precursor).

same level as in the latter. Notice that MS attains lower values in the Tadjidjar section, and that the accumulation rate is much higher compared to that in Huangling. This agreement seems impossible to be due to chance and indicated a more than regional but continental dimension. It suggested that the loess-palaeosol alternation in China and Tadjikistan corresponds to glacial-interglacial cycles.

Many investigations showed that the MBB was recorded in general in loess unit L8 and not in S8, but often in different stratigraphic positions and often displaying multiple reversals with or without intermediate directions (Torii *et al.* 1984, Rutter *et al.* 1991, Sun *et al.* 1993, Zhu & Tschu 2001).

In 1991, Hus and Han drew the attention to the fact that the MBB was recorded during the interglacial corresponding with MIS 19 in the deep-sea site ODP677 but, on the contrary, during a cold period in loess unit L8 in the Chinese Loess Plateau, and they attributed this discrepancy to a variable lock-in depth of the remanent magnetisation.

Although it would have been indicated to verify the astronomical or Milankovitch theory of climatic changes by geological records, the opposite approach was followed instead. As a fine timescale was lacking for the geological records, in the marine as well as in the continental realm, marine oxygen isotope curves and magnetic susceptibility of loess-palaeosol sequences were tuned to insolation changes, driven by variations in the orbital parameters of the earth, using the recorded reversal boundaries as tie markers (Berger 1988, Maher & Thompson 1999). This opened the search for signals in the MS records of loess-palaeosol sequences at about 100,000 years for eccentricity, at 41,000 years for obliquity and at about 20,000 years for precession, or of the pacemakers of climatic changes. Using standard spectral analysis methods, Wang *et al.* (1990) recognized the eccentricity and obliquity signals in a tuned loess-palaeosol sequence at Baoji. A strong peak in the frequency spectrum was found by Florindo *et al.* (1999) at about 21,000 years, in the Duanjiapo section near Lanzhou, characterised by a higher accumulation rate.

A refined timescale for the loess deposits in northern China to some 2.6 myr, with an accuracy of an individual precession cycle, was obtained by Heslop *et al.* (2000), relying on correlation of monsoon proxy records (the geomagnetic polarity stratigraphy at Baoji by Ding *et al.* (1994) and the magnetic susceptibility profile at Luochuan by Lu *et al.* (1999)), with astronomical solutions of Laskar (1990) and the benthonic oceanic ODP677 $\delta^{18}O$ record of Shackleton *et al.* (1990). This timescale, obtained by linking the monsoon variations with the global ice volume variations, demonstrated a downward displacement of the recorded reversal boundaries in loess deposits with respect to the climatic record. This shift is, as already mentioned above, probably related to the magnetisation lock-in depth and/or chemical overprinting.

One of the main outcomes was that probably thirty-seven interglacial-glacial cycles occurred during the last 2.5 myr, of global rather than of regional character, at least in the Northern Hemisphere (Fang *et al.* 1999). Amongst the best palaeoclimate archives on the continent are indeed loess-palaeosol deposits. In northern China, the alternation of loess units and interbedded palaeosol units provide a record reflecting climatic changes between glacial and interglacial monsoon regimes. The less weathered loess was mainly deposited in cold and dry conditions during glacial periods when Northern Hemisphere insolation was low and the East Asian summer monsoon weakened, leading to increasing dust falls during spring and summer. During interglacials, palaeosols developed by pedogenic and weathering processes under warmer and more humid conditions caused by the summer monsoon with lower dust-fall rates. There is general agreement at present for a strengthening of the summer monsoon southerly winds during interglacial periods and a strengthening of the north-west winds related to the Mongolian anticyclone during glacials.

The onset of aeolian loess accumulation on the Loess Plateau has been extended backwards in time, when much older loess-like sediments were found in Lingtai, indicating that cooling in the Northern Hemisphere may have started at least 7 myr ago (Ding *et al.* 1999). More recently, Guo *et al.* (2002) claimed that desertification probably started already 22 million years ago. But stronger arguments are needed besides grain size and chemical element analysis to enforce the idea that the origin of these sediments is windblown dust in which soils developed.

4. Palaeomagnetic Time Markers

Palaeomagnetic dating is based on our knowledge of the behaviour of the geomagnetic field in the past and hence does not provide absolute dates. Secular field variations, which are by definition changes of the main geomagnetic field of internal origin, cover a wide spectrum from millions of years to a few years. They include reversals, excursions and short-time variations in field direction and field intensity.

During the Cenozoicum, geomagnetic field reversals occurred with an average frequency of 4 per myr (fig. 7). They are global (worldwide) and synchronous. Reversal boundaries are well dated for the last 5 myr and can thus be used in turn for dating purposes. The reversal timescale proposed by Mankinen and Dalrymple in 1979 was based on field polarity determinations of volcanic rocks dated by the K-Ar method. Recorded reversal boundaries were used as key reference ages to tie $\delta^{18}O$ deep-sea records to insolation curves as predicted by the changes in the orbital parameters of the earth as well as to models of ice-volume or ice-sheet changes (Shackleton *et al.* 1990, Bassinot *et al.* 1994). It was the comparison with the astronomical timescale which led to a revised reversal timescale by Candé and Kent in 1992. The new proposed ages were confirmed by ^{39}Ar-^{40}Ar datings of lava flows with known magnetic polarity (Baksi 1992).

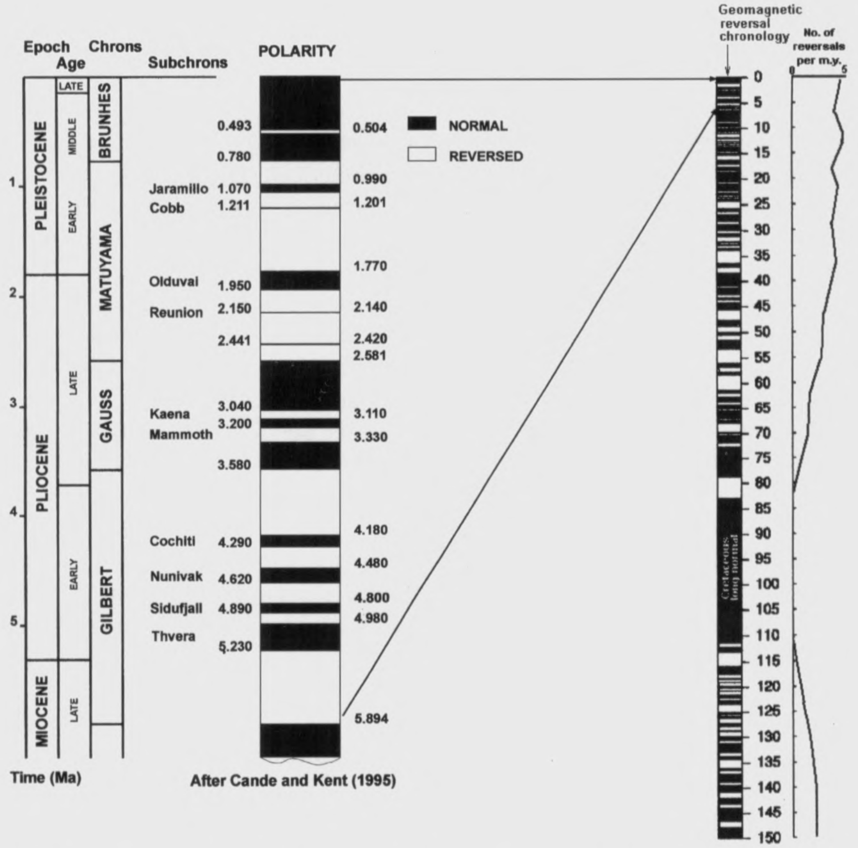


Fig. 7. — Geomagnetic polarity timescale for the last 6 myr and 150 myr (after Cande & Kent 1995, modified).

Geomagnetic field excursions were defined as large departures from the geocentric axial dipole field with virtual geomagnetic pole displacements of more than 45° from the geographic pole. Field excursions are still a matter of dispute because they lack spatial and temporal consistency. They may represent large amplitude secular variations, abortive reversals or, as Champion *et al.* (1988) claimed, short-time reversals. Lund *et al.* (1998) provided evidence for at least fourteen field excursions during the Brunhes chron, or last 780 myr. Their use in loess deposits is limited because of their short duration and great difficulty to trace them. Indeed, the time interval for a reversal to complete may be less than 1 Ka (Nowaczyk *et al.* 1994). On the other hand, if they can be revealed in loess deposits with high sedimentation rates, they may provide very useful time constraints for climatic changes recorded in these sediments.

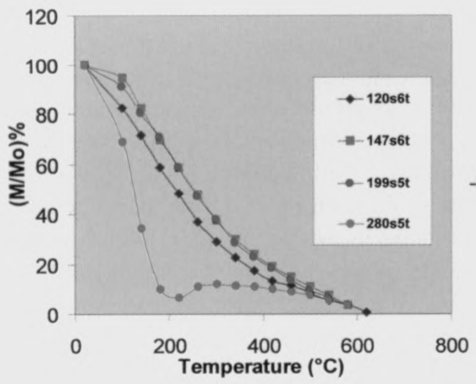
Only the Blake event that is dated at about 115 kyr has been reported in loess deposits in the western part of the Chinese Loess Plateau where sedimentation rate was high. It was found by ZHU *et al.* (1994) as a succession of three reversed short intervals between S1-3 and S1-2 in Ximing. On the contrary, FANG *et al.* (1997) detected it in Lanzhou as two reversed short intervals at the top of the last interglacial soil S1-c, equivalent to MIS 5e in deep-sea records, and ZHU *et al.* (1999) discovered it in Weinan as two distinct intervals of anomalous directions accompanied by a low intensity. A satisfying explanation for the different signatures and discrepancy in stratigraphic position is still lacking.

Short-term secular changes in direction and intensity of the geomagnetic field will probably play a minor role in loess deposits. Major problems are the uncertain nature of the remanent magnetisation in loess, the large overprinting by a viscous remanent magnetisation (VRM) that spontaneously occurs by thermal activation at normal temperature in the presence of a field, the time averaging and smoothing of the records, and the regional character of the secular variation, changing from place to place. As the geomagnetic field is mainly a dipole field, and the time-averaged field corresponds to a centric dipole, the dipole moment (called the virtual dipole moment) can be calculated knowing the local magnetic inclination and intensity. In many sediments, however, the natural remanent magnetisation (NRM) intensity not only reflects the field intensity, but is strongly modulated by climatic changes (WOLLIN *et al.* 1971).

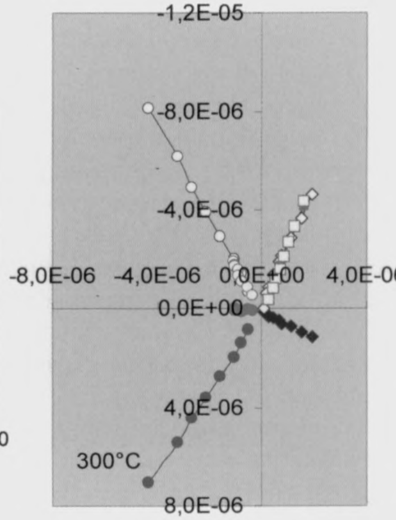
5. The Matuyama/Brunhes Transition in Luochuan and Remanent Magnetisation Mechanism in Loess and Palaeosols

The Matuyama/Brunhes (MB) reversal is not only an important stratigraphic marker, but better knowledge of the field behaviour during a reversal is needed for modelling the origin of the field. The MBB has been located in the middle or lower middle part of loess unit L8, in most loess sequences of the Chinese Loess Plateau examined so far. If the MB reversal happened to occur during the interglacial MIS 19, then it is expected to occur in soil unit S7. This time difference can be explained by a delay between deposition and fixation of the remanent magnetisation in loess. Based on a non-linear lock-in model, SPASSOV *et al.* (2003) estimated the delay at 22 kyr in the Lingtai section.

Oriented samples were taken by the author in 2002, in units S7, L8 and S8 of the Potou section in the type locality Luochuan, to examine the MB reversal in detail. Concentration dependent magnetic properties and magnetic hysteresis properties demonstrated magnetic enhancement in the soil units and gradual changes from bottom to top in loess unit L8, without any outliers. Anisotropy of magnetic susceptibility showed a normal magnetic fabric in the three units, with the maximum and intermediate susceptibility directions confined to the horizontal plane (HUS 2003). The stable remanent magnetisation of the samples was iso-



(a)



(b)

Fig. 8. — (a) Thermal demagnetisation curves, or the ratio of the initial to the residual remanence after each demagnetisation step, of samples from the Potou section in Luochuan containing respectively a normal, inverse and intermediate stable component. (b) The end-point of the magnetisation vector after treatment at 300 °C follows a straight line passing through the origin in all the samples as is shown in the orthogonal projection plots. In these diagrams, solid and open symbols represent the projection of the end-point of the magnetisation vector respectively on the local horizontal plane and vertical plane containing the N-S direction for each demagnetisation step.

lated by stepwise thermal demagnetisation at increasing temperatures. A single stable remanent magnetisation component could be isolated by heating the samples above 300 °C. Figure 8 shows demagnetisation curves of different samples containing respectively normal, inverse and intermediate stable components. The end-point of the magnetisation vector, beyond 300 °C, follows a straight line passing through the origin in all the samples as is shown in the orthogonal projection plots. In these diagrams solid and open symbols represent the projection of the end-point of the magnetisation vector, for each demagnetisation step, respectively on the local horizontal plane and vertical plane containing the N-S direction. The direction of the stable magnetisation component, determined by its declination and inclination, was obtained applying principal component analysis for three temperature steps and is given in figure 9 with the maximum angular deviation (MAD). Multiple reversals with intermediate directions occur in L8 (negative inclinations and large swings in declination). The corresponding virtual geomagnetic poles are not randomly distributed but confined to a belt centred on the 180° meridian, suggesting that the record is indeed a field record.

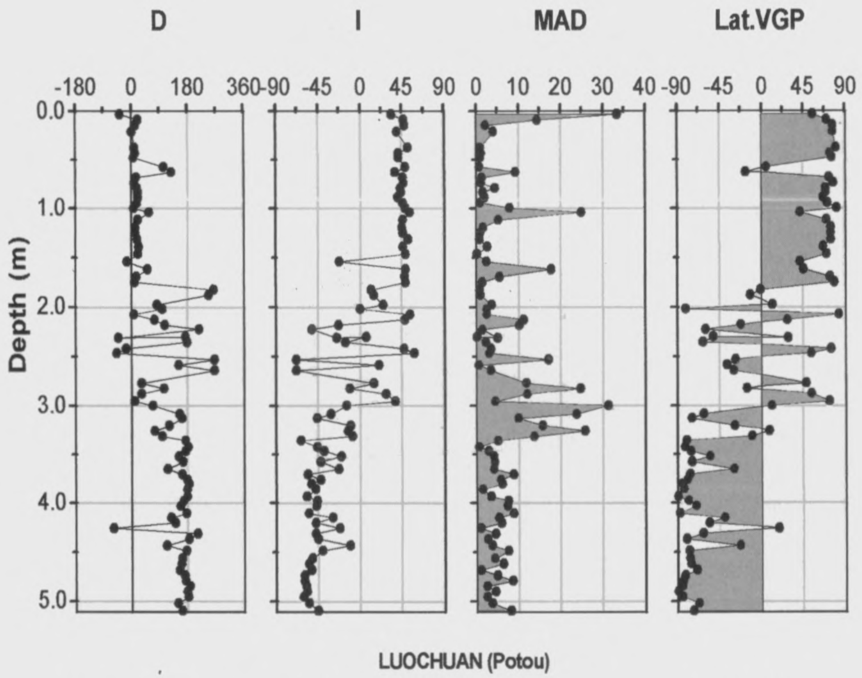


Fig. 9. — Variation of magnetic declination, inclination, maximum angular deviation (MAD) and latitude of the virtual geomagnetic pole (VGP) in units S7, L8 and S8 of the Potou section in Luochuan.

All investigations of the transitional period of the MB reversal in the loess deposits of China point to a complex field recording history, which can only be unravelled if the exact nature of the magnetic remanence carriers is known, a problem that has often been overlooked. Indeed, the magnetic mineralogy of the Chinese loess has been addressed with great attention, but the remanence acquisition mechanisms in loess and soils remains poorly understood. The absence of frost wedges and cryoturbated features in the Chinese loess indicates that is was rather dry during the glacial periods. It can hardly be imagined that loess deposited in cold and dry conditions may acquire a detrital or depositional remanent magnetisation (DRM) due to field alignment, because the hydrodynamic forces are much stronger than the magnetic aligning forces. Nevertheless, KRAVCHINSKIY (1970) demonstrated in a laboratory experiment that magnetic particles smaller than 200 μm become aligned along the field lines when settled in air, or at least that a bias occurs in the field direction. Is it really a DRM that was observed, or merely a VRM that spontaneously occurred due to thermal activation at normal temperature in the ambient field? Temporary reduction of the constraining forces, due to an increase in the water content or tremors, may lead to field alignment and the acquisition in a post-depositional remanent magnetisation (PDRM). The occurrence of multiple normal magnetozones in L8 rather suggests chemical overprinting and the presence of a chemical remanent magnetisation (CRM). This may have occurred by some degree of syngenetic soil formation during loess deposition or otherwise when the overlying soil S7 developed during stage MIS 19. In L8, MS and the ratio saturation remanence over saturation magnetisation decrease gradually from bottom to top, with small-scale variations superposed on it. The question is whether these variations are linked to changes in the wind strength or in some way related to soil formation instead. The authigenic formed ferrimagnetic minerals during soil development (see later), whether by lithological and/or biological processes, acquire a CRM when their grainsize exceeds the superparamagnetic/stable single domain threshold. If a DRM was initially present in the parent loess, in which the soil developed, it probably was nearly completely destroyed or randomized by weathering and bioturbation. The presence of a thick calcrete layer at the bottom of S7 indicates dissolution and illuviation of the calcium-carbonates during soil formation. Secondary calcium-carbonate filaments and spots are present in L8. Also weathering of iron-bearing minerals and dissolution of Fe^{2+} occurred as is indicated by the depletion of iron-bearing minerals, such as amphiboles, in the soils compared to the loess. Taking into account that loess is highly porous, how deep did translocation affect the loess profile of L8? Even during interglacials, deposition and dust storms not completely ceased. The alternation of dry and wet periods may have resulted in the formation of strong magnetic minerals according to one of the Le Borgne effects and finally a CRM (Le Borgne 1955). Although it is taken for granted that the palaeosols contain a CRM, and the less weathered loess a PDRM and/or CRM, more investigations are needed to solve this hanging problem. Comparison with the western part of the Loess Plateau, where soil development was less intense and accumulation rate higher, may be the clue to answer these questions.

6. Magnetic Susceptibility as a Climate Proxy

6.1. Definition of Magnetic Susceptibility

Magnetic Susceptibility (MS) measures the ease with which a material can be magnetised in a magnetic field. If a weak magnetic field, of the order of the geomagnetic field intensity (about 50μT), is applied to a demagnetised rock sample, a magnetisation will be induced which disappears when the field is removed. The ratio of the induced volume magnetisation (expressed in A/m in SI units) to the inducing field is called the volume susceptibility and is a dimensionless quantity (Thompson & Oldfield 1986). Mass specific susceptibility is the magnetisation per unit of weight over the field. Hence, mass MS is the volume MS divided by the density and has the dimension of the inverse of density. In very weak fields, or in the reversible part of a virgin magnetisation curve, MS may be considered as nearly independent of the field.

MS depends mainly on the chemical composition, concentration and grain sizes of the magnetic minerals present, but also on their magnetic, mechanical and thermal history and hence is a structure-sensitive rock magnetic parameter. The most important loess building materials, quartz, feldspar and carbonates, are diamagnetic and have a weak, negative MS, while many iron-bearing silicates behave like a paramagnetic and possess a weak but positive MS (THOMPSON & OLDFIELD 1986). When present, MS will be mainly determined by ferrimagnetic particles such as iron-oxides, characterised by a high and positive MS. MS depends on the concentration of the magnetic minerals in the sample, and in case of a single ferrimagnetic mineral occurring as spherical grains, it will reflect the volume or weight fraction of the ferrimagnetic mineral. It depends also on the grain size and is low in very small grains due to thermal activation. Very high values occur near the superparamagnetic/stable single domain threshold, where MS attains a minimum (DUNLOP & OZDEMIR 1997). Above the stable single domain/multidomain boundary, MS slightly increases with an increase in grain size. MS can be easily, quickly and non-destructively measured on an undisturbed sample, cored or cut into a cylindrical or cubic shape, but also on fragments or powders.

Iron is one of the most abundant elements on earth and very mobile. Iron compounds that are magnetic are therefore of the most common natural materials, forming about 2 % of the earth crust. During the cycles of transfer of materials in the hydrosphere, lithosphere and atmosphere, the magnetic particles contained in them may be subjected to many processes. Major processes of interest here are chemical transformation, physical processes of transport and deposition, concentration and dilution. The magnetic particles, and thus MS, may inform us about these processes and about the environmental conditions.

6.2. ORIGIN OF THE MAGNETIC SUSCEPTIBILITY ENHANCEMENT IN PALAEOSOLS

As mentioned in chapter 3, MS was used successfully to correlate loess-palaeosol sections and proved to be very useful to detect soils or traces of soil development, which escaped observation in the field (HAN *et al.* 1991). MS turned out to be high in the soils compared to the parent loess, often with a contrast by a factor 2 and higher (HELLER & EVANS 1995). The same holds for the magnetic remanence properties, suggesting a higher concentration of ferrimagnetic minerals in the soils than in the loess (HUS & HAN 1991, 1992).

Several models have been proposed to explain the enhanced magnetic properties, especially of MS, in palaeosols of the loess-palaeosol sequence in northern China:

— **Alteration and compaction model**
(HELLER & LIU 1984)

Dissolution of minerals (carbonates, etc.)
Loading

— **Dilution model**
(KUKLA 1987, KUKLA *et al.* 1988, 1990)
Constant input of highly magnetic high-level dust
Variable input of low magnetic low-level dust

— **Pedogenic model**
(ZHOU *et al.* 1990, LIU *et al.* 1990, MAHER & THOMPSON 1991)
Weathering
Authigenic formation of fine-grained magnetic minerals

— **Natural fires model**
(KLETETSCHKA & BANERJEE 1995)
Transformation of weakly magnetic minerals into strong magnetic minerals caused by fires in the presence of organic matter

— **Decomposition of organic material**
(MENG *et al.* 1997)
Ultrafine magnetite production by decomposition of organic material

Compaction has an influence on the volume MS, but the contrast in MS between loess and soils persists when using the mass specific MS instead (HUS & HAN 1991). Dissolution of weakly magnetic minerals alone, such as calcium-carbonates, cannot explain the high contrast in MS by more than a factor 2 between the loess and soils. Indeed, pure calcium-carbonate has a mass specific susceptibility of only -48. 10^{-8} m^3 kg^{-1} and the maximum initial content in loess did not exceed 20-25 %. The dilution model cannot be the main cause because the flux of cosmic dust is low (HUS & HAN 1992). The natural fires model by KLETETSCHKA & BANERJEE (1995) is a rediscovery of the Le Borgne effect that was well known in the fifties by scientists mastering the French language (LE BORGNE 1955). Le Borgne showed that natural fires may enhance the magnetic properties of the topsoil, due to reduction of magnetically weak iron compounds towards strongly magnetic magnetite in the presence of organic matter. This is followed by oxidation towards strong ferrimagnetic maghemite at the end of the burning process when oxygen enters the fire (LE BORGNE 1955). The soil magnetic enhancement in this case depends on the frequency of natural fires and hence would be different from place to place in the same soil unit.

In reality one has to take all the models into account, but the high MS contrast between soils and parent loess, which is observed in Asia and also in Central and Eastern Europe, can only be explained if new magnetic minerals formed during soil formation, or by the pedogenic model of ZHOU *et al.* (1990). Rock magnetic measurements on grainsize fractions indicate that the soils are indeed enriched in fine-grained magnetites near the threshold of superparamagnetic/stable single-domain behaviour (HUS & BATER 1993).

It is therefore important to know the nature and magnetic state of the magnetic minerals contributing to MS and the remanence. Mössbauer spectra on magnetically enriched samples show that in the palaeosoils, as well as in the loess, the

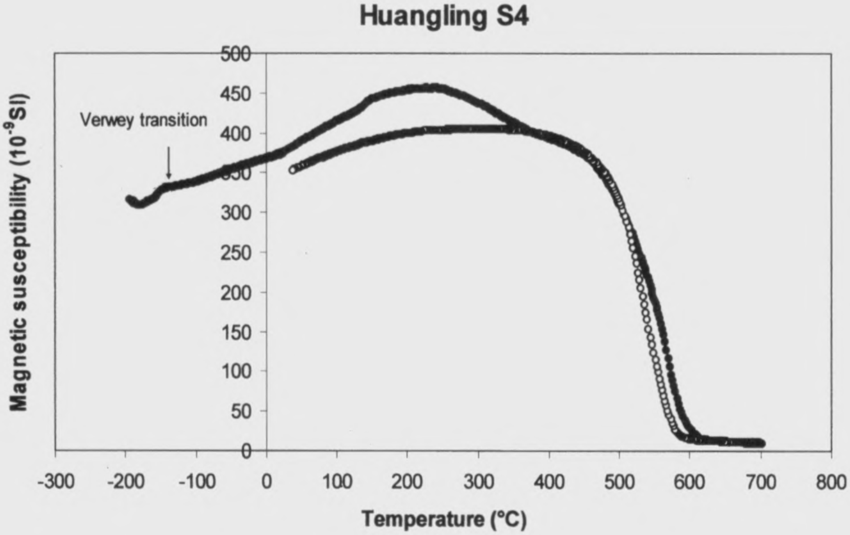


Fig. 10. — Magnetic susceptibility versus temperature of a magnetically enriched sample of soil unit S4 in Huangling. The fast decrease above 500 °C and inflection near the Curie temperature of 585 °C of pure magnetite indicate magnetite as the principal magnetic mineral present. An indication that this magnetite was not completely induced during the heating cycle is the increase observed at about -150 °C due to the Verwey transition of magnetite (solid dots: heating curve; open dots: cooling curve).

main magnetic minerals are magnetite, oxidised magnetite, hematite and goethite and that the soils contain more oxidised magnetites and maghemite compared to the parent loess (Han *et al.* 1991, Vandenberghe *et al.* 1998). Because of their weak magnetic properties, hematite and goethite are more difficult to detect, but unblocking temperatures above 600 °C point to the presence of hematite in the loess as well as in the soils. That magnetite is the principal magnetic mineral in the loess and in the soils is revealed by the Curie temperature close to 585 °C in MS-T curves, or close to the Curie temperature of pure magnetite. This is shown in figure 10 for a magnetically enriched sample of soil unit S4 in Huangling. An indication that the magnetite was originally present, and not completely induced during the heating cycle, is the increase observed at -150 °C due to the Verwey transition of magnetite.

Two models have been proposed for the origin of the authigenically formed strong magnetic minerals in soils: lithological and biological neo-formation (Maher & Thompson 1999). The latter may give rise to biologically induced magnetite (BIM) when Fe-reducing bacteria are present and intracellular biologically organized magnetite (BOM) produced by magnetotactic bacteria (Maher & Thompson 1992, 1995). BOM's can be distinguished from detrital magnetites due to their morphology and their property to form magnetic chains. BOM's are not abundant in loess deposits, but a few have been detected in soil unit S1 in China (Maher & Thompson 1995). In a sample from the modern topsoil from Jiacun near Baoji, collected by the author, Dr N. Petersen of the University of Munich was able to show the presence of BIM's (Petersen, personal communication). Inorganic or lithological *in situ* formation of ultrafine-grained magnetite has been reported by Maher & Taylor (1988) in some contemporary English soils in the humid temperate zone.

Soil magnetic enhancement does not always occur. In some areas, like Canada and Siberia, the opposite is found; instead of an enhancement of MS in the soils, a decrease is noticed (Beget *et al.* 1990, Chlachula *et al.* 1999). This will happen when deposition is close to the source area and when soil development is weak (Evans 2001). Depending on the nature of the source material, the loess may in some areas contain a high concentration of coarse-grained magnetites, when deposited close to the source area, and be characterised by a high MS. During soil formation, the combined effect of weathering and dilution by weakly magnetic organic matter, will cause the bulk MS to become less in the soils compared to the parent loess.

In areas close to the icecap, or periglacial areas, as was the case for Belgium during the last glacial, pedogenic magnetites may dissolve and nearly completely disappear from the soil profile (Hus & Geeraerts 1986).

Neither of the models mentioned above, which were initially proposed for the soil magnetic enhancement observed in the Chinese Loess Plateau, can explain solely the MS enhancement of palaeosols in general. Although pedogenesis is probably the most important cause, it only partially accounts for the enhancement in several cases and different physical, chemical and biological processes must be taken into account (Hus & Han 1992, Sun & Liu 2000).

7. The Palaeoclimatic Significance of Magnetic Susceptibility in the Loess Plateau of China

The loess-palaeosol sequence of the Loess Plateau in China is a witness of the palaeomonsoon history and it is thought that the increase in MS contrast between parent loess and soils from soil unit S5 to the present soil, as shown in figure 6 for the Huangling section, is due to a strengthening of the palaeomonsoon regime (An *et al.* 1991a,b). In summer, the S-E monsoon, due to a high pressure cell above Australia and the Western Pacific, may give rise to high precipitation on the Loess Plateau when S-E winds meet the colder N-E air masses. In winter, the Loess Plateau is invaded by cold, dry winds from the N-W due to the Siberian high (the greatest high in the world up to 1,040 hPa). These winds carry dust from the Tengger and Mu Us deserts in the north of the Loess Plateau that settles in the area of the Loess Plateau (fig. 2). MS of the soils would thus be an indicator of past summer monsoon regimes. On the other hand, the grainsize of the loess is controlled by the intensity of winter monsoon winds (Ding *et al.* 1999).

Not only glacial-interglacial cycles are reflected in the MS signature of the Chinese Loess Plateau, but even millennial-scale changes have been revealed in the western part of the Loess Plateau, where sedimentation rates are higher and the loess thickness exceeds 300 m for the last 1.2 myr (Chen *et al.* 1997, Fang *et al.* 1999). MS variations for the last 60,000 years in the loess deposits in the Lanzhou area could be correlated with the temperature records of the Vostok ice core in Antarctica and Grip ice cores of Greenland.

Magnetic susceptibility changes in loess deposits thus confirmed many of the climatic changes recorded in deep-sea sediments (glacial-interglacial cycles and the Heinrich events in the North Atlantic) and in ice cores in Antarctica and Greenland (Dansgaard-Oeschger cycles and Bond cycles) (Heller & Evans 1995, Maher & Thompson 1999). But they also pointed to discrepancies between the astronomical theory of climatic changes and changes of the proxies of the climate, known as the 100 kyr and 400 kyr problems (Hus & Han 1991, Elkibbi & Rial 2001).

The aforementioned observations suggest a close relation between MS of soils and soil formation and hence indirectly with climate. Any soil property S is a function of climate (cl), vegetation (o), topography (r), parent material (p) and time (t): S = f (cl, o, r, p, t) (Jenny 1941). In order to identify the effect of any single factor, like climate, on a soil property (such as MS) all the remaining factors have to be kept constant. The loess parent material in the Loess Plateau of China is quite uniform and originates from the deserts north of the Loess Plateau. Topography (p) varies little and vegetation (v) co-varies with climate (cl). In this case, S becomes a function of time and climate only, where time represents the duration of weathering. The Loess Plateau in China therefore lends itself quite well as a test region to look for a relation between MS and climate. When S is the magnetic susceptibility of the soil, the pedogenic magnetic susceptibility (K_{ped}) has to be isolated, as only this component is related to climate. One has to determine how the latter builds up in time, or otherwise stated, to know the rate of change of K_{ped} and the duration of weathering or residence time in the weathering zone. Some investigators think that soils develop very quickly and hence also K_{ped}, others on the contrary claim that the residence time in the weathering zone may be very long.

Previous investigations suggested a relation between K_{ped} of the palaeosols and the present-day precipitation, based on a linear correlation between bulk MS of palaeosol unit S5 and present-day mean annual precipitation on the Loess Plateau (Liu *et al.* 1991). Soil S5 was chosen as it is a marker horizon, easy recognizable and displaying the strongest soil formation. This choice can be criticised as S5 is in reality a soil complex with three distinct soils separated by loess, and because the present-day precipitation and palaeoprecipitation when S5 was formed are probably unrelated (see also fig. 3a). A palaeoprecipitation model was proposed by HELLER *et al.* (1993) for the last glacial-interglacial period in Luochuan using paired measurements of MS and the cosmogenic ^{10}Be radionuclide that is produced in the upper atmosphere. The pedogenic MS was determined using the assumption by BEER *et al.* (1995) that the detrital flux component of the total beryllium flux is proportional to the magnetic susceptibility of detrital origin. MAHER & THOMPSON (1994, 1995) obtained K_{ped} by taking the difference between bulk MS and MS of the least weathered loess unit L9 instead, and calculated the palaeorainfall using a linear transfer function from the modern soil MS- rainfall relationship.

In all the models proposed, calibration is needed by looking for modern equivalents. On the Loess Plateau of northern China, the modern soils have MS values comparable with palaeosols. Apparently, there seems to be a relation between MS of the modern soils and precipitation and temperature. Annual average precipitation (MAP) varies from more than 600 mm to less than 100 mm over the Loess Plateau and average annual temperature (MAT) from 6 to 13 °C (PORTER *et al.* 2001). There is a sixfold increase in MS, from 30 10^{-8} to 200 10^{-8}, from the southern margin of the Mu Us desert to the northern margin of the Qinling Shan mountains.

There are many pitfalls and difficulties to face when establishing climofunctions. It is hard to find places on the Loess Plateau where the modern soil did not undergo anthropogenic influences. Moreover, there should be no confusion between the modern soil and Holocene soils (fig. 11). Localities on the Chinese Loess Plateau with a long record of climatic parameters are limited and for mean annual evaporation either scarce or absent. Nevertheless, encouraging results were obtained by HAN *et al.* (1996) and by MAHER & THOMPSON (1999), but using the bulk MS of the modern soil. PORTER *et al.* (2001) found an exponential relationship between MS and the product of MAT with MAP.

As data was lacking in the transition area between the western and central part of the Loess Plateau, the topsoil and parent material was sampled in 2002 by the author in thirteen places (distance between stations about 30-40 km) along a SE-NW transect from Baoji to Zhonding. Some extra difficulties were encountered; in some areas soils developed in Tertiary deposits and soil formation was very weak in the northern part of the profile. Figure 11 points to a complex relationship between MS and mean annual precipitation along this transect.

From the previous investigations it is evident that climofunctions or transfer functions must be established for different regions. Not bulk MS should be used, as only the pedogenic magnetic susceptibility K_{ped} is linked to the climate. All minerals contribute to bulk MS that can be written as $K = K_{dia} + K_{para} + K_{ferri}$ or also $K = K_{ped} + K_{loess\ dust}$, with the second term in the last expression corresponding to the susceptibility of the least weathered loess. On basis of coercive force spectra derived from isothermal or anhysteretic remanent magnetisation acquisition and/or demagnetisation curves, EYRE (1966) and later SPASSOV *et al.* (2003) were able to distinguish respectively 2 (1) pedogenic components and 2 (3) detrital

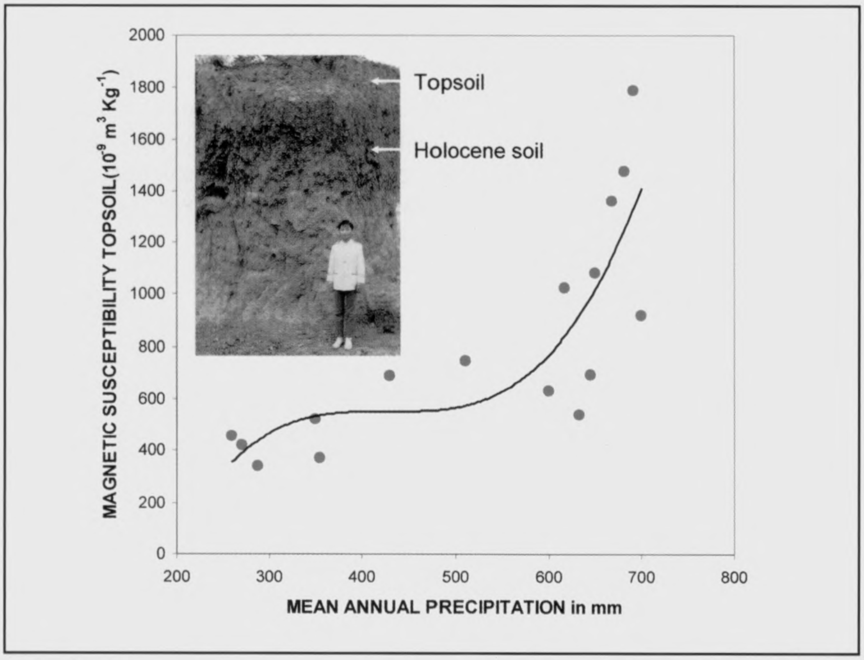


Fig. 11. — Variation of MS with mean annual precipitation along a SE-NW transect from Baoji to Zhonding. Each dot represents the average MS of the topsoil from two stations a few m apart.

components in palaeosols. Moreover, the strength of the MS signal, depending on the intensity of pedogenesis, varies in time and with depth, and the rate of dust accumulation.

8. Conclusion

Geomagnetic field reversals recorded in loess-palaeosol deposits of the Chinese Loess Plateau are important chronostratigraphic time markers and tie markers to link proxy climatic records to marine records and to insolation curves as predicted by the astronomical theory of climate changes. However, the delay between deposition and fixation of the remanence, estimated to be about 22 kyr for the MB reversal, and the occurrence of multiple reversals must be taken into account. The exact remanence acquisition mechanism remains unclear but examination of the BM reversal in Luochuan points to chemical overprinting and associated CRM's.

Magnetic susceptibility is a powerful rock magnetic parameter to trace changes of the magnetic particle content in sediments caused by environmental and climatic changes. Magnetic susceptibility changes in loess-palaeosol sequences suggest that it is a proxy of climate, but the mechanism by which it becomes a climate proxy remains controversial. The modern soils on the Loess Plateau of China indicate a close relation between magnetic susceptibility with precipitation and temperature. Only the pedogenic susceptibility is related to climate and has to be isolated from the lithogenic and anthropogenic components. In favourable cases unmixing of magnetisation acquisition curves allows to discriminate different magnetic fractions of different origin.

ACKNOWLEDGEMENTS

The palaeomagnetic study of the Potou section in Luochuan was supported by grant MO/34/008 from the "Diensten van de Eerste Minister, Wetenschappelijke Technische en Culturele Aangelegenheden (DWTC)", Belgium.

REFERENCES

AN, Z. S., KUKLA, G. J., PORTER, S. C. & XIAO, J. 1991a. Late Quaternary dust flow on the Chinese loess plateau. — *Catena*, **18**: 125-132.

AN, Z. S., KUKLA, G. J., PORTER, S. C. & XIAO, J. 1991b. Magnetic susceptibility evidence of monsoon variation on the loess plateau of central China during the last 130,000 years. — *Quaternary Research*, **36**: 29-36.

BAKSI, A. 1992. $^{40}Ar/^{39}Ar$ dating of the Brunhes-Matuyama geomagnetic field reversal. — *Science*, **256**: 356-357.

BASSINOT, F., LABEYRIE, L., VINCENT, E., QUIDELEUR, X., SHACKLETON, N. & LANCELOT, Y. 1994. The astronomical theory of climate and the age of the Brunhes-Matuyama magnetic reversal. — *Earth and Planetary Science Letters*, **126**: 91-108.

BEER, J., SHEN, C. D., HELLER, F., LIU, T. S., BONANI, G., DITTRICH, B., SUTER, M. & KUBIK, P. W. 1993. ^{10}Be and magnetic susceptibility in Chinese loess. — *Geophysical Research Letters*, **20**: 57-60.

BEGET, J. E., STONE, D. B. & HAWKINS, D. B. 1990. Palaeoclimatic forcing of magnetic susceptibility variations in Alaskan loess during the Late Quaternary. — *Geology*, **18**: 40-43.

BERGER, A. 1988. Milankovitch theory and climate. — *Reviews of Geophysics*, **26**: 624-657.

CANDE, S. C. & KENT, D. V. 1992. A new geomagnetic polarity timescale for the Late Cretaceous and Cenozoic. — *Journal of Geophysical Research*, **97**: 13917-13951.

CATT, J. 1986. Soils and Quaternary Geology: A Handbook for Field Scientists. — Oxford (England), Clarendon Press, 267 pp.

CHAMPION, D. E., LAMPHERE, M. A. & KUNTZ, M. A. 1988. Evidence for a new geomagnetic reversal from lava flows in Idaho: Discussion of short polarity reversals in the Brunhes and late Matuyama polarity chron. — *Journal of Geophysical Research*, **93**: 11667-11680.

CHEN, F. H., BLOEMENDAL, J., WANG, J. M., LI, J. J. & OLDFIELD, F. 1997. High-resolution multiproxy climate records from Chinese loess: Evidence for rapid climatic changes over the last 75 kyr. — *Palaeogeography, Palaeoclimatology, Palaeoecology*, **130**: 323-335.

CHLACHULA, J., EVANS, M. E. & RUTTER, N. W. 1999. A magnetic investigation of a Late Quaternary loess/palaeosol record in Siberia. — *Geophysical Journal International*, **132**: 128-132.

DERBYSHIRE, E. 1983. On the Morphology, sediments, and the origin of the loess plateau of central China. — *In*: GARDNER, R. & SCOGING, H. Mega-Geomorphology, Oxford (England), Clarendon Press, pp. 172-194.

DING, Z. L., XIONG, S. F., SUN, J. M., YANG, S. L., GU, Z. Y. & LIU, T. S. 1999. Pedostratigraphy and palaeomagnetism of a ~7.0 Ma eolian loess-red clay and the implications for palaeomonsoon evolution. — *Palaeogeography, Palaeoclimatology Palaeoecology*, **152**: 49-66.

DING, Z., YU, Z., RUTTER, N. W. & LIU, T. 1994. Towards an orbital timescale for Chinese loess deposits. — *Quaternary Science Reviews*, **13**: 39-70.

DUNLOP, D. J. & OZDIMIR, O. 1997. Rock Magnetism. Fundamentals and frontiers. — Cambridge, Cambridge University Press, 573 pp.

ELKIBBI, M. & RIAL, J. A. 2001. An outsider's review of the astronomical theory of the climate: is the eccentricity-driven insolation the main driver of the ice ages. — *Earth Science Reviews*, **56**: 161-177.

EVANS, M. E. 2001. Magnetoclimatology of aeolian sediments. — *Geophysical Journal International*, **144**: 495-497.

EYRE, J. K. 1996. The application of high resolution IRM acquisition to the discrimination of remanence carriers in Chinese loess. — *Studia geophysica et geodetica*, **40**: 234-242.

FANG, X. M., LI, J. J., BANERJEE, S. K., JACKSON, M., OCHES, E. A. & VAN DER VOO, R. 1999. Millennial-scale climatic change during the last interglacial period: Superparamagnetic sediment proxy from palaeosol S1, western Chinese loess plateau. — *Geophysical Research Letters*, **26**: 2485-2488.

FANG, X. M., VAN DER VOO, R., MAC NIOCAILL, C., DAI, X.-R., KEMP, R. A., DERBYSHIRE, E., CAO, J.-X., WANG, J.-M. & WANG, G. 1997. A record of the Blake event during the last interglacial paleosol in the western Loess Plateau of China. — *Earth and Planetary Science Letters*, **146**: 73-82.

FLORINDO, F., ZHU, R., GUO, B., YUE, L., PAN, Y. & SPERANZA, F. 1999. Magnetic proxy climate results from the Duanjiapo loess section¸ southernmost extremity of the Chinese loess plateau. — *Journal of Geophysical Research*, **104**: 645-659.

GUO, Z. T., RUDDIMAN, W. F., HAO, Q. Z., WU, H. B., QIAO, Y. S., ZHU, R. X., PENG, S. Z., WEI, J .J., YUAN, B. Y. & LIU, T. S. 2002. Onset of desertification by 22 Myr ago inferred from loess deposits in China. — *Nature*, **416**: 159-163.

HAN, J., HUS, J. J., PAEPE, R., VANDENBERGHE, R. & LIU, T. S. 1991. The Rock Magnetic Properties of the Malan and Lishi Formations in the Loess Plateau of China. — *In*: LIU, T.S. *et al.*, Loess, Environment and Global Change. Beijing (China), Science Press, pp. 30-47.

HAN, J., LU, H., WU, N. & GUO, Z. 1996. The magnetic susceptibility of modern soils in China and its use for paleoclimate reconstructions. — *Studia geophysica et geodaetica*, **3**: 262-275.

HELLER, F. & EVANS, M. E. 1995. Loess Magnetism. — *Reviews of Geophysics*, **33**: 211-240.

HELLER, F. & LIU, T. S. 1982. Magnetostratigraphical dating of loess deposits in China. — *Nature*, **300**: 431-433.

HELLER, F. & LIU, T. S. 1984. Magnetism of Chinese loess deposits. — *The Geophysical Journal of the Royal Astronomical Society*, **77**: 125-141.

HELLER, F., SHEN, C. D., BEER, J., LIU, X. M., LIU, T. S., BRONGER, A., SUTTER, M. & BONANI, G. 1993. Quantitative estimates and paleoclimatic implications of pedogenic ferromagnetic minerals formation in Chinese loess. — *Earth and Planetary Science Letters*, **114**: 385-390.

HESLOP, D., LANGEREIS, C. G. & DEKKERS, M. J. 2000. A new astronomical timescale for the loess deposits of Northern China. — *Earth and Planetary Science Letters*, **184**: 125-139.

HOVAN, S. A., REA, D. K., PISIAS, N. G. & SHACKLETON, N. 1989. A direct link between the China loess and marine $\delta^{18}O$ records: aeolian flux to the north Pacific. — *Nature*, **340**: 296-298.

HUS, J. 2003. The Magnetic Fabric of some Loess/Palaeosol Deposits. — *Physics and Chemistry of the Earth*, **28**: 689-699.

HUS, J. J. & BATER, B. 1993. Magnetic hysteresis parameters of bulk samples and particle-size fractions of the loess/palaeosol sequence in Central China. — *Geologica Carpathica*, **44** (5): 325-333.

HUS, J. J. & GEERAERTS, R. 1986. Palaeomagnetic and rock magnetic investigation of Late Pleistocene loess deposits in Belgium. — *Physics of the Earth and Planetary Interiors*, **44**: 21-40.

HUS, J. J. & HAN, J. 1991. The magnetic susceptibility profile of the loess-palaeosol sequence in North Central China - a proxy measure of climate. — *Acta Geologica Taiwanica*, **24**: 1991 57-76.

HUS, J. J. & HAN, J. M. 1992. The contribution of loess magnetism in China to the retrieval of past global changes: some problems. — *Physics of the Earth and Planetary Interiors*, **7**: 154-168.

JENNY, H. 1941. Factors of Soil Formation. — New York, McGraw-Hill, 281 pp.

KLETETSCHKA, G. & BANERJEE, S. K. 1995. Magnetic stratigraphy of Chinese loess as a record of natural fires. — *Geophysical Research Letters*, **22**: 1341-1343.

KRAVCHINSKIY, A. Y. 1970. Magneto-granulometric classes of clastic sediments. — *Izv. Earth Physics*, **12**: 102-104, 816-817.

KUKLA, G. J. 1987. Loess stratigraphy in Central China. — *Quaternary Science Reviews*, **6**: 191-219.

KUKLA, G. & AN, Z. S. 1989. Loess stratigraphy in Central China. — *Palaeogeography, Palaeoclimatology, Palaeoecology*, **72**: 203-225.

KUKLA, G., AN, Z. S., MELIECE, L., GAVIN, G. & XIAO, J. L. 1990. Magnetic susceptibility record of Chinese Loess. — *Transactions of the Royal Society of Edinburgh: Earth Sciences*, **81**: 263-288.

KUKLA, G., HELLER, F., LIU, X. M., KU, T. C., LIU, T. S. & AN, Z. S. 1988. Pleistocene climates in China dated by magnetic susceptibility. — *Geology*, **16**: 811-814.

LASKAR, J. 1990. The chaotic motion of the solar system: A numerical estimate of the size of the chaotic zones. — *Icarus*, **88**: 266-291.

LE BORGNE, E. 1955. Abnormal magnetic susceptibility of the topsoil. — *Annales de Géophysique*, **11**: 399-419.

LIU, T. S. & CHANG, T. H. 1964. The "Huangtu" (loess) of China. — *Rep. VI Int. Congr. Quat. Warsaw*, **4**: 503-524.

LIU, X. M., LIU, T. S., HELLER, F. & XU, T. C. 1990. Frequency-dependent susceptibility of loess and Quaternary palaeoclimate. — *Quaternary Science*, **1**: 41-50.

LIU, X. M., LIU, T. S., SHAW, J., HELLER, F., XU, T. X. & YUAN, B. Y. 1991. Paleomagnetic and Paleoclimatic Studies of Chinese Loess. — *In*: LIU, T. S. *et al.*, Loess, Environment and Global Change. Beijing (China), Science Press, pp. 61-81.

LU, H., LIU, X., ZHANG, F., AN, Z. & DODSON, J. 1999. Astronomical calibration of loess-paleosol deposits at Luochuan central Chinese loess plateau. — *Palaeogeography, Palaeoclimatology, Palaeoecology*, **154**: 237-246.

LUND, S. P., ACTON, G., CLEMENT, B., HASTEDT, M., OKADA, M., WILLIAMS, T. & the ODP Leg 172 Scientific Party 1998. Geomagnetic field excursions occurred often during the last million years. — *EOS, Transactions American Geophysical Union*, **79**: 178-179.

MAHER, B. A. & TAYLOR, R. M. 1988. Formation of ultrafine-grained magnetite in soils. — *Nature*, **336**: 368-370.

MAHER, B. A. & THOMPSON, R. 1991. Mineral magnetic record of the Chinese loess and paleosols. — *Geology*, **19**: 3-6.

MAHER, B. A. & THOMPSON, R. 1992. Paleoclimatic Significance of the Mineral Magnetic Record of the Chinese Loess and Paleosols. — *Quaternary Research*, **37**: 155-170.

MAHER, B. A. & THOMPSON, R. 1994. Pedogenesis and palaeoclimate: interpretation of the magnetic susceptibility record of Chinese loess-palaeosol sequences: comment. — *Geology*, **22**: 857-858.

MAHER, B. A. & THOMPSON, R. 1995. Paleorainfall Reconstructions from Pedogenic Magnetic Susceptibility Variations in the Chinese Loess and Palaeosols. — *Quaternary Research*, **44**: 383-391.

MAHER, B. A. & THOMPSON, R. 1999. Quaternary Climates, Environments and Magnetism. — Cambridge, Cambridge University Press, 390 pp.

MANKINEN, E. A. & DALRYMPLE, G. B. 1979. Revised geomagnetic polarity time scale for the interval 0-5 Myr BP. — *Journal of Geophysical Research*, **84**: 615-626.

MENG, X. M., DERBYSHIRE, E. & KEMP, R. A. 1997. Origin of the magnetic susceptibility signal in Chinese loess. — *Quaternary Science Reviews*, **16**: 833-839.

NOWACZYK, N. R., FREDERICHS, T. W., EISENHAUER, A. & GARD, G. 1994. Magnetostratigraphic data from late Quaternary sediments from the Yermak Plateau, Arctic Ocean: evidence for four geomagnetic polarity events within the last 170 Ka of the Brunhes Chron. — *Geophysical Journal International*, **117**: 453-471.

PORTER, S. C., HALLET, B., WU, X. & AN, Z. 2001. Dependence of Near-Surface Magnetic Susceptibility on Dust Accumulation Rate and Precipitation on the Chinese Loess Plateau. — *Quaternary Research*, **55**: 271-283.

PYE, K. 1987. Aeolian Dust and Dust Deposits. — San Diego (California), Academic Press, 334 pp.

RUTTER, N. W., DING, Z. L., EVANS, M. E. & LIU, T. S. 1991. Baoji-type pedostratigraphic section, loess plateau, north-central China. — *Quaternary Science Reviews*, **10**: 1-22.

SHACKLETON, N. J., BERGER, A. & PELTIER, W. R. 1990. An alternative astronomical calibration of the Lower Pleistocene timescale based on ODP site 677. — *Transactions of the Royal Society of Edinburgh: Earth Sciences*, **81**: 251-261.

SMALLEY, I. J. 1966. The properties of glacial loess and the formation of loess deposits. — *Journal of Sedimentary Petrology*, **36**: 669-676.

SMALLEY, I. J., JEFFERSON, I. F., DIJKSTRA, T. A. & DERBYSHIRE, E. 2001. Some major events in the development of the scientific study of loess. — *Earth-Science Reviews*, **54**: 5-18.

SPASSOV, S., HELLER, F., EVANS, M. E., YUE, L. P. & VON DOBENECK, T. 2003. A lock-in model for the complex Matuyama-Brunhes boundary record of the loess/palaeosol sequence at Lingtai (Central Chinese Loess Plateau). — *Geophysical Journal International*, **155**: 350-366.

SPASSOV, S., HELLER, F., KRETZSCHMAR, R., EVANS, M. E., YUE, L. P. & NOURGALIEV, D. K. 2003. Detrital and pedogenic magnetic mineral phases in the loess/palaeosol sequence at Lingtai (Central Chinese Loess Plateau). — *Physics of the Earth and Planetary Interiors*, **140**: 255-275.

SUN, J. M. & LIU, T. S. 2000. Multiple origins and interpretations of the magnetic susceptibility signal in Chinese wind-blown sediments. — *Earth and Planetary Science Letters*, **180**: 287-296.

SUN, D. H., SHAW, J., AN, Z. S. & ROLPH, T. 1993. Matuyama/Brunhes (M/B) transition recorded in Chinese loess. — *Journal of Geomagnetism and Geoelectricity*, **45**: 319-330.

THOMPSON, R. & MAHER, B. A. 1995. Age models, sediment fluxes and palaeoclimatic reconstructions for the Chinese loess and palaeosol sequences. — *Geophysical Journal International*, **123**: 611-622.

THOMPSON, R. & OLDFIELD, E. 1986. Environmental Magnetism. — London, Allen and Umwin, 227 pp.

TORII, M., YUE, L. P., HAYASHIDA, A., MAENAKA, K., YOKOYAMA, T. & SASAJIMA, S. 1984. Natural remanent magnetization of loess-palaeosol deposits in Luochuan area. — *In*: SASAJIMA, S. & WANG, Y. Y., The Recent Research on Loess in China, Kyoto (Japan), Kyoto University, pp. 32-41.

VANDENBERGHE, R. E., HUS, J. J. & DE GRAVE, E. 1998. Evidence from Mössbauer spectroscopy of neo-formation of magnetite/maghemite in the soils of loess/paleosol sequences in China. — *Hyperfine Interactions*, **117**: 359-369.

VON RICHTHOVEN, F. 1882. On the mode of origin of the loess. — *Geological Magazine*, **9**: 293-305.

WANG, Y., EVANS, M. E., RUTTER, N. & DING, Z. 1990. Magnetic susceptibility of Chinese loess and its bearing on palaeoclimate. — *Geophysical Research Letters*, **17**: 2449-2451.

WANG, Y. Y. & SONG, H. L. 1983. Rock desert, gravel desert, sand desert, loess, Shaanxi. — China, People's Art Publishing House.

WOLLIN, G., ERICSON, D. B., RYAN, W. B. F. & FOSTER, J. H. 1971. Magnetism of the earth and climatic changes. — *Earth and Planetary Science Letters*, **12**: 175-183.

ZHOU, L. P., OLDFIELD, F., WINTLE, A. G., ROBINSON, S. G. & WANG, J. T. 1990. Partly pedogenic origin of magnetic variations in Chinese loess. — *Nature*, **346**: 737-739.

ZHU, R. X., PAN, Y. X. & LIU, Q. S. 1999. Geomagnetic excursions recorded in Chinese loess in the last 70,000 years. — *Geophysical Research Letters*, **26**: 505-508.

ZHU, R. X. & TSCHU, K.-K. 2001. Studies on Palaeomagnetism and Reversals of Geomagnetic Field in China. — Beijing (P. R. China), Science Press, 168 pp.

ZHU, R. X., ZHOU, L. P., LAJ, C., MAZAUD, A. & DING, Z. L. 1994. The Blake geomagnetic polarity episode recorded in Chinese loess. — *Geophysical Research Letters*, **21**: 697-700.

ELOGE — LOFREDE

Bull. Séanc. Acad. R. Sci. Outre-Mer
Meded. Zitt. K. Acad. Overzeese Wet.
51 (2005-3): 347-349

Pierre SALMON

(Liège, 30 novembre 1926 — Bruxelles, 10 mars 2005)*

Le 10 mars 2005, nous avons perdu l'un de nos confrères, des plus présents, des plus assidus, et des plus impliqués dans notre Académie.

Pierre Salmon était né à Liège le 30 novembre 1926. Après avoir terminé ses études secondaires au lycée d'Ixelles, qui a abrité beaucoup de personnes ayant plus tard fait carrière, il entra à l'ULB. Il y obtint une licence en philosophie et lettres, groupe Histoire, en juillet 1950, puis l'agrégation de l'enseignement moyen du degré supérieur, et enfin le doctorat en 1961. Plus tard, en revenant à l'ULB comme professeur, il marquera et l'enseignement de l'histoire et celui de l'agrégation.

Lauréat des bourses de voyages en 1951, il séjourna à *l'Academia Belgica* de Rome et en 1953-54 fut pensionnaire de l'Ecole Normale Supérieure de Paris où il consacra son temps à la rédaction de sa thèse de doctorat sur la politique égyptienne d'Athènes aux VI^e^ et V^e^ siècles avant J.-C. Il acquit à la rue d'Ulm, comme il l'a écrit lui même, «le scrupule du travail poussé à fond, le souci de clarté, le sens presque indéfinissable de la fantaisie, le goût du paradoxe, la liberté de se développer sans être moulé dans un seul schéma idéologique et l'ouverture à la culture des autres».

La carrière pédagogique de Pierre Salmon commença à l'Athénée Léon Lepage (1950-1963). Il devait conserver de cette période le souci de la communication claire et la minutie. Puis, il entra à l'Institut d'Enseignement Supérieur Lucien Cooremans (1961-1978). En 1963, il intégrait le Centre Universitaire de l'Etat à Anvers et l'ULB en 1970. C'est à l'ULB que son ancien professeur, Pierre Gourou, devait jouer un rôle déterminant dans sa carrière. «Comme il

* Eloge prononcé à la séance de la Classe des Sciences morales et politiques tenue le 17 novembre 2005.

assurait la direction de la 8e section du centre scientifique et médical de l'ULB en Afrique centrale (CEMUBAC), il me proposa de participer à une enquête interdisciplinaire sur l'ethnie Zande dans le Nord-est du Congo et me confia l'histoire de la politique de l'administration belge à l'égard du problème Zande depuis 1908. Cette importante mission accomplie au Congo allait modifier l'orientation de ma carrière».

Le travail sur la politique égyptienne d'Athènes lui avait déjà fait mettre un pied sur le continent africain; avec le CEMUBAC il devenait partie intégrante de l'Afrique qu'il a tant aimée et qui le lui a bien rendu. Les liens scientifiques et amicaux qu'il y noua furent innombrables et les lettres que nous recevons encore aujourd'hui à l'Institut de Sociologie, les témoignages d'amitié comme les regrets exprimés à son décès, illustrent le lien particulier qu'il avait avec les Africains au-delà des frontières et du temps.

Les missions d'enseignement et de recherches se succédèrent: en Egypte, en Tunisie, au Maroc, au Congo, au Rwanda, au Burundi, au Soudan, en Zambie, au Zimbabwe, en Afrique du Sud, au Cameroun, en Côte-d'Ivoire, au Sénégal, au Niger, au Nigeria, au Togo et, ces dernières années, surtout au Burkina Faso et au Bénin.

Pierre l'Africain était infatigable.

A l'ULB comme professeur, il enseigna surtout à la faculté des sciences sociales, politiques et économiques: la société et les institutions de l'Antiquité, l'ethnohistoire de l'Afrique, et la critique historique.

Tous autant de cours qui marqueront des générations. A la suite de son admission à l'honorariat, il continua encore à dispenser un cours sur le racisme.

A la faculté SOCO, il fut aussi président de la Section des sciences sociales, président de l'Agrégation et un des piliers du Certificat en coopération au développement, aujourd'hui DES en coopération au développement.

A l'ULB, Pierre Salmon intégra également, en 1971, le Centre d'études africaines, centre dont il devint plus tard directeur. Il était à l'Institut de Sociologie un des membres les plus actifs et contribua à maintes reprises à une de ses revues, *Civilisations*, qui lui consacra deux numéros en hommage lors de son admission à la retraite.

Pierre Salmon a beaucoup donné à l'ULB, non seulement en tant qu'enseignant, mais également en participant à son administration (1976-1978) comme président de Section (1976-1978), conseiller du Recteur pour les problèmes de coopération (1989-1992), secrétaire général du Conseil de la Coopération (1991). Et aussi en participant au rayonnement de cette université en sillonnant la Belgique et le monde pour y donner des conférences et des cours.

Il fut élu membre associé de notre Académie en 1973, puis en 1977 devint membre titulaire de la Classe des Sciences morales et politiques. Il fut à l'origine de l'entrée à l'Académie de beaucoup d'entre nous, toujours soucieux de faire reconnaître les personnes à qui il avait accordé sa confiance et qu'il avait honorées de son estime.

Il fut également membre correspondant de l'Académie Européenne des Sciences, des Arts et des Lettres dès 1982, qu'il affectionnait particulièrement.

Savant authentique, infatigable, exigeant avec lui-même, honnête, rigoureux, appliquant l'esprit critique qu'il enseignait, il avait aussi la modestie du vrai savant. Il nous a laissé une œuvre abondante, impossible à énumérer, mais dont je citerai ici trois livres qui m'ont marquée: Histoire et Critique (1969); Le racisme devant l'Histoire (1973); Introduction à l'Histoire de l'Afrique (1986).

Lorsqu'il nous a quittés, il corrigeait la première épreuve de la dernière édition de l'Histoire de l'Afrique qu'il voulait publier sous le titre de: «Nouvelle Histoire de l'Afrique» qui devrait paraître dans les mois qui viennent.

Mais Pierre Salmon n'était pas seulement un savant. C'était aussi un homme remarquable.

Fils attentif et serviable, il a été pour sa mère jusqu'à la fin de vie de cette dernière un soutien et une aide remarquable. Il a aussi été un père et un mari aimant, un ami fidèle, un professeur soutenant toujours les étudiants les plus vulnérables, encourageant et guidant ceux qui se tournaient vers lui, un homme ayant toujours un petit mot pour tous ceux qu'il rencontrait.

J'ai personnellement connu Pierre Salmon comme étudiante en 1975. J'ai été son assistante en ethnohistoire de l'Afrique, en critique historique et à l'agrégation. Il a été mon maître, mon guide, reprenant inlassablement sa devise: «Ecrire, publier, toujours travailler». Je lui dois mon entrée à l'ULB, mon entrée à l'Académie, et je lui suis reconnaissante pour son amitié et sa préoccupation.

Pierre Salmon, humaniste, révolté par l'injustice, et épris de vérité, n'est plus, mais il aura marqué tous ceux qui ont eu la chance de le connaître.

Firouzeh Nahavandi

PROCES-VERBAUX — NOTULEN

Classe des Sciences morales et politiques
Classe des Sciences naturelles et médicales
Classe des Sciences techniques

Séance commune du 19 avril 2005

(Extrait du procès-verbal)

La séance est ouverte à 14 h 30 par M. M. De Dapper, Président de l'Académie et Directeur de la Classe des Sciences naturelles et médicales, assisté de M. P. Collard, Directeur de la Classe des Sciences morales et politiques, M. J. Roos, Directeur de la Classe des Sciences techniques, et Mme D. Swinne, Secrétaire perpétuelle.

Membres de la Classe des Sciences morales et politiques présents: Mme P. Bouvier, MM. F. de Hen, E. Haerinck, J. Jacobs, C. Sturtewagen, Mme Y. Verhasselt, membres titulaires; M. H. Vinck, membre correspondant.

Membres de la Classe des Sciences naturelles et médicales présents: MM. J. Bouharmont, E. Coppejans, M. Deliens, P. Gigase, P. Goyens, J.-M. Jadin, H. Nicolaï, A. Ozer, G. Stoops, J.-J. Symoens, L. Tack, P. Van der Veken, membres titulaires; M. M. Erpicum, membre associé.

Membres de la Classe des Sciences techniques présents: MM. L. André, J.-M. Charlet, G. Demarée, R. Leenaerts, J. Michot, A. Monjoie, membres titulaires; MM. D. Demaiffe, M. Van Den Herrewegen, membres associés.

Ont fait part de leur regret de ne pouvoir assister à la séance: M. R. Anciaux, Mme D. de Lame, MM. D. Demolin, G. de Villers, R. Devisch, Mme M. Engelborghs-Bertels, MM. P. Halen, J. Klener, Mme F. Nahavandi, MM. P. Raymaekers, A. Stenmans, E. Vandewoude, C. Willemen, *membres de la Classe des Sciences morales et politiques*; MM. J. Alexandre, I. Beghin, J. Belot, J. Bolyn, J.-P. Descy, L. D'Haese, A. Fain, S. Geerts, H. Maraite, J. Meyer, S. Pattyn, Mme F. Portaels, MM. E. Robbrecht, D. Thys van den Audenaerde, R. Tonglet, E. Van Ranst, Mme M. Vincx, *membres de la Classe des Sciences naturelles et médicales*; MM. P. Beckers, J. Berlamont, J. Debevere, J. De Cuyper, H. Deelstra, L. Dejonghe, J.-J. Droesbeke, A. Lejeune, J. Marchal, H. Paelinck, J. Poesen, *membres de la Classe des Sciences techniques.*

M. M. De Dapper souhaite la bienvenue à tout le monde à cette séance extraordinaire de l'Académie. Il rappelle l'événement survenu le 26 décembre 2004 en Indonésie et la solidarité internationale qui s'en est suivie. Interpellée par cette catastrophe naturelle, l'Académie a tenu à organiser la séance commune de ce jour.

Klasse voor Morele en Politieke Wetenschappen
Klasse voor Natuur- en Geneeskundige Wetenschappen
Klasse voor Technische Wetenschappen

Gemeenschappelijke zitting van 19 april 2005

(Uittreksel van de notulen)

De zitting wordt om 14 u. 30 geopend door de Heer M. De Dapper, Voorzitter van de Academie en Directeur van de Klasse voor Natuur- en Geneeskundige Wetenschappen, bijgestaan door de Heer P. Collard, Directeur van de Klasse voor Morele en Politieke Wetenschappen, de Heer J. Roos, Directeur van de Klasse voor Technische Wetenschappen, en Mevr. D. Swinne, Vast Secretaris.

Aanwezige leden van de Klasse voor Morele en Politieke Wetenschappen: Mevr. P. Bouvier, de HH. F. de Hen, E. Haerinck, J. Jacobs, C. Sturtewagen, Mevr. Y. Verhasselt, werkende leden; de Heer H. Vinck, corresponderend lid.

Aanwezige leden van de Klasse voor Natuur- en Geneeskundige Wetenschappen: de HH. J. Bouharmont, E. Coppejans, M. Deliens, P. Gigase, P. Goyens, J.-M. Jadin, H. Nicolaï, A. Ozer, G. Stoops, J.-J. Symoens, L. Tack, P. Van der Veken, werkende leden; de Heer M. Erpicum, geassocieerd lid.

Aanwezige leden van de Klasse voor Technische Wetenschappen: de HH. L. André, J.-M. Charlet, G. Demarée, R. Leenaerts, J. Michot, A. Monjoie, werkende leden; MM. D. Demaiffe, M. Van Den Herrewegen, geassocieerde leden.

Betuigden hun spijt niet aan de zitting te kunnen deelnemen: de Heer R. Anciaux, Mevr. D. de Lame, de HH. D. Demolin, G. de Villers, R. Devisch, Mevr. M. Engelborghs-Bertels, de HH. P. Halen, J. Klener, Mevr. F. Nahavandi, de HH. P. Raymaekers, A. Stenmans, E. Vandewoude, C. Willemen, *leden van de Klasse voor Morele en Politieke Wetenschappen*; de HH. J. Alexandre, I. Beghin, J. Belot, J. Bolyn, J.-P. Descy, L. D'Haese, A. Fain, S. Geerts, H. Maraite, J. Meyer, S. Pattyn, Mevr. F. Portaels, de HH. E. Robbrecht, D. Thys van den Audenaerde, R. Tonglet, E. Van Ranst, Mevr. M. Vincx, *leden van de Klasse voor Natuur- en Geneeskundige Wetenschappen*; de HH. P. Beckers, J. Berlamont, J. Debevere, J. De Cuyper, H. Deelstra, L. Dejonghe, J.-J. Droesbeke, A. Lejeune, J. Marchal, H. Paelinck, J. Poesen, *leden van de Klasse voor Technische Wetenschappen.*

De Heer Morgan De Dapper heet iedereen welkom op deze buitengewone zitting van de Academie. Hij herinnert aan wat er op 26 december 2004 in Indonesië is gebeurd en aan de daaropvolgende internationale solidariteit. Deze natuurramp kon de Academie niet onberoerd laten; vandaar deze gemeenschappelijke zitting.

M. T. Camelbeeck présente une communication intitulée «Le séisme géant de subduction de Sumatra-Andaman du 26 décembre 2004: leçons pour une alerte efficace des tsunamis».

M. E. Coppejans présente une communication intitulée «Minder gekende gevolgen van de tsoenami en plaatselijke follow-up in Sri-Lanka».

Mme M. Nicolai présente une communication intitulée «MSF Response to the Tsunami Disaster».

M. M. De Dapper remercie les conférenciers.

Les procès-verbaux des séances du 15, 22 et 31 mars 2005 sont approuvés à l'unanimité.

La séance est levée à 17 h 30.

De Heer T. Camelbeeck stelt een mededeling voor met als titel „Le séisme géant de subduction de Sumatra-Andaman du 26 décembre 2004: leçons pour une alerte efficace des tsunamis”.

De Heer E. Coppejans stelt een mededeling voor met als titel „Minder gekende gevolgen van de tsunami en plaatselijke follow-up in Sri-Lanka”.

Mevr. M. Nicolai stelt een mededeling voor met als titel „MSF Response to the Tsunami Disaster”.

De Heer M. De Dapper dankt de sprekers.

De notulen van de zittingen van 15, 22 en 31 maart 2005 worden eenparig goedgekeurd.

De zitting wordt om 17 u. 30 geheven

Classe des Sciences morales et politiques

Séance du 17 mai 2005

(Extrait du procès-verbal)

La séance est ouverte à 14 h 30 par M. P. Collard, Directeur, assisté de Mme F. Nahavandi, Vice-Directeur, et de Mme D. Swinne, Secrétaire perpétuelle.

Sont en outre présents: M. H. Baetens Beardsmore, Mme P. Bouvier, MM. F. de Hen, J. Jacobs, J. Klener, C. Sturtewagen, membres titulaires; MM. D. Demolin, C. Ntampaka, Mme B. Vanhoudt, MM. F. Van Noten, C. Willemen, membres associés; M. H. Vinck, membre correspondant.

Ont fait part de leur regret de ne pouvoir assister à la séance: M. R. Anciaux, Mme D. de Lame, MM. P. de Maret, R. Deliège, G. de Villers, Mme M. Engelborghs-Bertels, MM. J. Everaert, P. Halen, A. Huybrechts, P. Petit, S. Plasschaert, A. Stenmans, J. Vanderlinden, G. Vanthemsche, J.-L. Vellut, Mme Y. Verhasselt.

Décès du R. P. Frans Bontinck

M. P. Collard annonce le décès, survenu à Zuun le 20 avril 2005, du R. P. Frans Bontinck, membre correspondant honoraire.

Il retrace brièvement la carrière du Confrère disparu.

La Classe observe une minute de silence à la mémoire du défunt.

M. J.-L. Vellut est désigné en qualité de rédacteur de l'éloge du R. P. Bontinck.

Aspects comparatifs des langues tupi

M. D. Demolin présente une communication intitulée comme ci-dessus.

MM. H. Vinck, J. Klener, H. Baetens Beardsmore, J. Jacobs et Mme B. Vanhoudt prennent part à la discussion.

La Classe décide de publier le texte dans le *Bulletin des Séances*.

La réforme du système judiciaire rwandais

M. C. Ntampaka présente une communication intitulée comme ci-dessus.

M. C. Sturtewagen, Mme P. Bouvier, M. H. Vinck et Mme B. Vanhoudt prennent part à la discussion.

La Classe décide de publier le texte dans le *Bulletin des Séances*.

Klasse voor Morele en Politieke Wetenschappen

Zitting van 17 mei 2005

(Uittreksel van de notulen)

De zitting wordt om 14 u. 30 geopend door de Heer P. Collard, Directeur, bijgestaan door Mevr. F. Nahavandi, Vice-Directeur, en door Mevr. D. Swinne, Vast Secretaris.

Zijn bovendien aanwezig: de Heer H. Baetens Beardsmore, Mevr. P. Bouvier, de HH. F. de Hen, J. Jacobs, J. Klener, C. Sturtewagen, werkende leden; de HH. D. Demolin, C. Ntampaka, Mevr. B. Vanhoudt, de HH. F. Van Noten, C. Willemen, geassocieerde leden; de Heer H. Vinck, corresponderend lid.

Betuigden hun spijt niet aan de zitting te kunnen deelnemen: de Heer R. Anciaux, Mevr. D. de Lame, de HH. P. de Maret, R. Deliège, G. de Villers, Mevr. M. Engelborghs-Bertels, de HH. J. Everaert, P. Halen, A. Huybrechts, P. Petit, S. Plasschaert, A. Stenmans, J. Vanderlinden, G. Vanthemsche, J.-L. Vellut, Mevr. Y. Verhasselt.

Overlijden van E. P. Frans Bontinck

De Heer P. Collard kondigt het overlijden aan, op 20 april 2005 te Zuun, van E. P. Frans Bontinck, erecorresponderend lid.

Hij schetst bondig de carrière van de overleden Confrater.

De Klasse neemt een minuut stilte waar ter nagedachtenis van de overledene.

De Heer J.-L. Vellut wordt aangeduid als opsteller van de lofrede van E. P. Bontinck.

„Aspects comparatifs des langues tupi"

De Heer D. Dumolin stelt een mededeling voor getiteld als hierboven.

De HH. H. Vinck, J. Klener, H. Baetens Beardsmore, J. Jacobs en Mevr. B. Vanhoudt nemen aan de bespreking deel.

De Klasse beslist de tekst in de *Mededelingen der Zttingen* te publiceren.

„La réforme du système judiciaire rwandais"

De Heer C. Ntampaka stelt een mededeling voor getiteld als hierboven.

De Heer C. Sturtewagen, Mevr. P. Bouvier, de Heer H. Vinck en Mevr. B. Vanhoudt nemen aan de bespreking deel.

De Klasse beslist de tekst in de *Mededelingen der Zittingen* te publiceren.

«The Fish Hunters of El-Hosh: Rock Art Research and Archaeological Investigations in Upper Egypt (1998-2004)»

M. D. Huyge a présenté cette communication lors de la séance du 18 janvier 2005.

Après avoir entendu les rapports, la Classe décide de publier ce texte dans le *Bulletin des Séances* moyennant l'application des remarques formulées par les rapporteurs.

Concours 2005

Un travail a été introduit régulièrement en réponse à la deuxième question du Concours 2005, intitulée: «On demande une étude originale sur les transformations actuelles, au sein d'une société africaine, des pratiques sociales de relation à l'environnement et des conceptions qui les sous-tendent», à savoir:

Van Tendeloo, A. 2004. Veranderingen in traditionele en commerciële mens-ecosysteemrelaties in de mangrovebaai van Gazi (Kenia): etnobiologie, percepties van de lokale gemeenschap en ecotoeristische activiteiten. — Thesis Vrije Universiteit Brussel, 161 pp. + 43 pp. (annexes).

Après avoir entendu les rapports de MM. R. Devisch, F. Malaisse et Mme Y. Verhasselt, la Classe décide de n'attribuer ni prix, ni mention honorable à ce travail.

La réunion est levée à 17 h.

„The Fish Hunters of El-Hosh: Rock Art Research and Archaeological Investigations in Upper Egypt (1998-2004)"

De Heer D. Huyge stelde deze mededeling voor tijdens de zitting van 18 januari 2005.

Na de verslagen te hebben gehoord, beslist de Klasse deze tekst in de *Mededelingen der Zittingen* te publiceren mits er rekening wordt gehouden met de opmerkingen van de verslaggevers.

Wedstrijd 2005

Eén werk werd regelmatig ingediend in antwoord op de tweede vraag van de Wedstrijd 2005: „Men vraagt een originele studie van de huidige veranderingen, in een Afrikaanse samenleving, van de sociale praktijken met betrekking tot de omgeving, en van de visies die er de basis van vormen", namelijk:

Van Tendeloo, A. 2004. Veranderingen in traditionele en commerciële mens-ecosysteemrelaties in de mangrovebaai van Gazi (Kenia): etnobiologie, percepties van de lokale gemeenschap en ecotoeristische activiteiten. — Thesis Vrije Universiteit Brussel, 161 blz. + 43 blz. (bijlagen).

Na de verslagen te hebben gehoord van de HH. R. Devisch, F. Malaisse en Mevr. Y. Verhasselt, beslist de Klasse noch prijs noch eervolle vermelding toe te kennen aan dit werk.

De vergadering wordt om 17 u. geheven.

Classe des Sciences naturelles et médicales

Séance du 24 mai 2005

(Extrait du procès-verbal)

La séance est ouverte à 14 h 30 par M. M. De Dapper, Directeur, assisté de Mme D. Swinne, Secrétaire perpétuelle.

Sont en outre présents: MM. J. Alexandre, I. Beghin, J. Bouharmont, E. De Langhe, P. Goyens, J.-M. Jadin, H. Maraite, J. Meyer, H. Nicolaï, G. Stoops, C. Sys, M. Wéry, membres titulaires; MM. R. Dudal, E. Roche, membres associés; M. R. Branckaert, membre correspondant.

Ont fait part de leur regret de ne pouvoir assister à la séance: MM. J. Belot, J.-P. Descy, A. Fain, S. Geerts, P. Gigase, P. Janssens, F. Malaisse, J.-C. Micha, A. Ozer, S. Pattyn, Mme F. Portaels, MM. J. Rammeloo, E. Robbrecht, J.-J. Symoens, L. Tack, R. Tonglet, P. Van der Veken, E. Van Ranst, Mmes Y. Verhasselt, M. Vincx.

Décès de M. André Lawalrée

M. M. De Dapper annonce le décès, survenu à Bruxelles le 18 avril 2005, de M. A. Lawalrée, membre associé honoraire.

Il retrace brièvement la carrière du Confrère disparu.

La Classe observe une minute de silence à la mémoire du défunt.

La Classe décide de solliciter M. E. Robbrecht pour la rédaction de l'éloge de M. A. Lawalrée. M. J. Rammeloo sera contacté au cas où M. E. Robbrecht ne pourrait accepter cette tâche.

«Geomorphology and Quaternary Geology of the Canyon Complex in the Wadi Mujib Basin (Jordan)»

Mme C. De Jaeger présente une communication intitulée comme ci-dessus.

MM. C. Sys, M. De Dapper, E. De Langhe et R. Dudal prennent part à la discussion.

Etant donné que le sujet de la communication de Mme C. De Jaeger est identique à celui de son étude primée lors du Concours 2004 et qu'à cette occasion, la Classe avait décidé de publier cette étude sous forme de mémoire, aucun rapporteur ne sera désigné.

Nominations

Par arrêté ministériel du 21 mars 2005, Mme M. Temmerman a été nommée membre associé.

Klasse voor Natuur- en Geneeskundige Wetenschappen

Zitting van 24 mei 2005

(Uittreksel van de notulen)

De zitting wordt om 14 u. 30 geopend door de Heer M. De Dapper, Directeur, bijgestaan door Mevr. D. Swinne, Vast Secretaris.

Zijn bovendien aanwezig: de HH. J. Alexandre, I. Beghin, J. Bouharmont, E. De Langhe, P. Goyens, J.-M. Jadin, H. Maraite, J. Meyer, H. Nicolaï, G. Stoops, C. Sys, M. Wéry, werkende leden; de HH. R. Dudal, E. Roche, geassocieerde leden; de Heer R. Branckaert, corresponderend lid.

Betuigden hun spijt niet aan de zitting te kunnen deelnemen: de HH. J. Belot, J.-P. Descy, A. Fain, S. Geerts, P. Gigase, P. Janssens, F. Malaisse, J.-C. Micha, A. Ozer, S. Pattyn, Mevr. F. Portaels, de HH. J. Rammeloo, E. Robbrecht, J.-J. Symoens, L. Tack, R. Tonglet, P. Van der Veken, E. Van Ranst, Mevr. Y. Verhasselt, M. Vincx.

Overlijden van de Heer André Lawalrée

De Heer M. De Dapper kondigt het overlijden aan, op 18 april 2005 te Brussel, van de Heer A. Lawalrée, eregeassocieerd lid.

Hij geeft een bondig overzicht van de carrière van de overleden Confrater.

De Klasse neemt een minuut stilte waar ter nagedachtenis van de overledene.

De Klasse beslist de Heer E. Robbrecht te vragen de lofrede van de Heer A. Lawalrée op te stellen. Indien de Heer E. Robbrecht deze taak niet zou kunnen aanvaarden, zal de Heer J. Rammeloo gecontacteerd worden.

„Geomorphology and Quaternary Geology of the Canyon Complex in the Wadi Mujib Basin (Jordan)"

Mevr. C. De Jaeger stelt een mededeling voor getiteld als hierboven.

De HH. C. Sys, M. De Dapper, E. De Langhe en R. Dudal nemen aan de bespreking deel.

Gezien het onderwerp van de mededeling van Mevr. C. De Jaeger identiek is aan haar studie bekroond in het kader van de Wedstrijd 2004 en de Klasse beslist heeft haar studie in de vorm van een verhandeling te publiceren, zal geen enkele verslaggever aangeduid worden.

Benoemingen

Bij ministerieel besluit van 21 maart 2005 werd Mevr. M. Temmerman tot geassocieerd lid benoemd.

Par arrêté ministériel du 21 mars 2005, M. S. García Jimenez a été nommé membre correspondant.

Le séisme géant de subduction de Sumatra-Andaman du 26 décembre 2004: leçons pour une alerte efficace des tsunamis

M. T. Camelbeeck a présenté cette communication lors de la séance commune du 19 avril 2005.

La Classe désigne le premier rapporteur.

Concours 2005

Un travail a été introduit régulièrement en réponse à la troisième question du Concours 2005, intitulée: «On demande une étude concernant l'évaluation des ressources naturelles pour l'agriculture dans un paysage montagneux d'Afrique tropicale», à savoir:

VERDOODT, A. 2003. Elaboration and Application of an Adjusted Agricultural Land Evaluation Model for Rwanda. — Proefschrift Universiteit Gent, vol. 1, 440 pp.; vol. 2, 60 pp. (annexes).

Après avoir entendu les rapports de MM. J. Bouharmont, H. Maraite et J. Meyer, la Classe décide d'attribuer le prix d'une valeur de 1 000,00 € à Mme A. Verdoodt de l'Université de Gand. Elle portera le titre de «Lauréat de l'Académie Royale des Sciences d'Outre-Mer».

Prix Jean-Jacques et Berthe Symoens 2005

Conformément à l'article 9 du règlement, la Commission de sélection du Prix a communiqué son rapport à la Classe des Sciences naturelles et médicales.

Trois travaux ont été régulièrement introduits:

MBEGA, J.-D. 2004. Biodiversité des poissons du bassin inférieur de l'Ogooué (Gabon). — Facultés Universitaires Notre-Dame de la Paix, Presses Universitaires de Namur, 2 vols, 614 pp.

STENUITE, S. 2003. Etude du phytoplancton du lac Tanganyika: production particulaire et dissoute. — Mémoire de licence en Sciences biologiques, Facultés Universitaires Notre-Dame de la Paix, Namur, 61 pp.

VROMANT, N., CHAU, N. T. H. & OLLEVIER, F. 2001.
— The effect of rice-seeding rate and fish stocking on the floodwater ecology of the rice field in direct-seeded, concurrent rice-fish systems. — *In: Hydrobiologia*, **445**: 151-164.
— The effect of rice-seeding rate and fish stocking on the floodwater ecology of the trench of a concurrent, direct-seeded rice-fish systems. — *In: Hydrobiologia*, **457**: 105-117.

Bij ministerieel besluit van 21 maart 2005 werd de Heer S. García Jimenez tot corresponderend lid benoemd.

„Le séisme géant de subduction de Sumatra-Andaman du 26 décembre 2004: leçons pour une alerte efficace des tsunamis"

De Heer T. Camelbeeck stelde deze mededeling voor tijdens de gemeenschappelijke zitting van 19 april 2005.

De Klasse duidt de eerste verslaggever aan.

Wedstrijd 2005

Eén werk werd regelmatig ingediend in antwoord op de derde vraag van de Wedstrijd 2005: „Men vraagt een studie betreffende de evaluatie van natuurlijke hulpbronnen voor de landbouw in een tropisch Afrikaans berglandschap", namelijk:

VERDOODT, A. 2003. Elaboration and Application of an Adjusted Agricultural Land Evaluation Model for Rwanda. — Proefschrift Universiteit Gent, vol. 1, 440 blz.; vol. 2, 60 blz. (bijlagen).

Na de verslagen van de HH. J. Bouharmont, H. Maraite en J. Meyer gehoord te hebben, beslist de Klasse de prijs ter waarde van 1 000,00 € aan Mevr. A. Verdoodt van de Universiteit Gent toe te kennen. Zij zal de titel van „Laureaat van de Koninklijke Academie voor Overzeese Wetenschappen" dragen.

Jean-Jacques en Berthe Symoensprijs 2005

Conform artikel 9 van het reglement heeft de Selectiecommissie van de Prijs haar verslag aan de Klasse voor Natuur- en Geneeskundige Wetenschappen overgemaakt.

Drie werken werden regelmatig ingediend:

MBEGA, J.-D. 2004. Biodiversité des poissons du bassin inférieur de l'Ogooué (Gabon). — Facultés Universitaires Notre-Dame de la Paix, Presses Universitaires de Namur, 2 vols, 614 pp.

STENUITE, S. 2003. Etude du phytoplancton du lac Tanganyika: production particulaire et dissoute. — Mémoire de licence en Sciences biologiques, Facultés Universitaires Notre-Dame de la Paix, Namur, 61 pp.

VROMANT, N., CHAU, N. T. H. & OLLEVIER, F. 2001.
— The effect of rice-seeding rate and fish stocking on the floodwater ecology of the rice field in direct-seeded, concurrent rice-fish systems. — *In: Hydrobiologia*, **445**: 151-164.
— The effect of rice-seeding rate and fish stocking on the floodwater ecology of the trench of a concurrent, direct-seeded rice-fish systems. — *In: Hydrobiologia*, **457**: 105-117.

Conformément à l'avis de la Commission, la Classe décide d'attribuer le prix d'une valeur de 2 500,00 € à M. J.-D. Mbega.

Le diplôme lui sera remis lors de la séance académique d'ouverture du 20 octobre 2005. L'auteur portera le titre de «Lauréat du Prix Jean-Jacques et Berthe Symoens de Limnologie tropicale».

La séance est levée à 16 h 15.

Conform het advies van de Commissie, beslist de Klasse de prijs ter waarde van 2 500,00 € aan de Heer J.-D. Mbega toe te kennen.

Het diploma zal hem tijdens de academische openingszitting van 20 oktober overhandigd worden. De auteur zal de titel van „Laureaat van de Jean-Jacques en Berthe Symoensprijs voor Tropische Limnologie" dragen.

De zitting wordt om 16 u. 15 geheven.

Classe des Sciences techniques

Séance du 26 mai 2005

(Extrait du procès-verbal)

La séance est ouverte à 14 h 30 par M. J. Roos, Directeur, assisté de M. J. Marchal, Vice-Directeur, et de Mme D. Swinne, Secrétaire perpétuelle.

Sont en outre présents: MM. P. De Meester, J.-J. Droesbeke, R. Leenaerts, W. Loy, H. Paelinck, R. Sokal, membres titulaires; M. A. Buldgen, membre associé; M. R. Branckaert, membre correspondant de la Classe des Sciences naturelles et médicales.

Ont fait part de leur regret de ne pouvoir assister à la séance: MM. P. Beckers, J. Berlamont, J.-M. Charlet, J. Charlier, J. Debevere, J. De Cuyper, H. Deelstra, L. Dejonghe, J. Delrue, G. Demarée, A. François, P. Goossens, A. Lejeune, L. Maertens, J. Michot, J. Poesen, W. Van Impe, M. Van Montagu, Mme Y. Verhasselt.

Eloge de M. André Deruyttere

M. P. De Meester prononce l'éloge de M. A. Deruyttere.

La Classe observe une minute de silence à la mémoire du Confrère disparu.

Le texte de cet éloge paraîtra dans le *Bulletin des Séances*.

Nominations

Par arrêté royal du 26 mars 2005, M. J. Berlamont a été nommé membre titulaire.

Par arrêté ministériel du 21 mars 2005, M. A. Gioda a été nommé membre correspondant.

Avenir de l'agriculture en Afrique de l'Ouest: le rôle des productions animales dans la partie centrale du Sénégal

M. A. Buldgen présente une communication intitulée comme ci-dessus.

MM. H. Paelinck, J.-J. Droesbeke, P. De Meester, R. Branckaert, R. Sokal et R. Leenaerts prennent part à la discussion.

La Classe décide de publier ce texte dans le *Bulletin des Séances*.

Klasse voor Technische Wetenschappen

Zitting van 26 mei 2005

(Uittreksel van de notulen)

De zitting wordt om 14 u. 30 geopend door de Heer J. Roos, Directeur, bijgestaan door de Heer J. Marchal, Vice-Directeur, en Mevr. D. Swinne, Vast Secretaris.

Zijn bovendien aanwezig: de HH. P. De Meester, J.-J. Droesbeke, R. Leenaerts, W. Loy, H. Paelinck, R. Sokal, werkende leden; de Heer A. Buldgen, geassocieerd lid; de Heer R. Branckaert, corresponderend lid van de Klasse voor Natuur- en Geneeskundige Wetenschappen.

Betuigden hun spijt niet aan de zitting te kunnen deelnemen: de HH. P. Beckers, J. Berlamont, J.-M. Charlet, J. Charlier, J. Debevere, J. De Cuyper, H. Deelstra, L. Dejonghe, J. Delrue, G. Demarée, A. François, P. Goossens, A. Lejeune, L. Maertens, J. Michot, J. Poesen, W. Van Impe, M. Van Montagu, Mevr. Y. Verhasselt.

Lofrede van de Heer André Deruyttere

De Heer P. De Meester spreekt de lofrede van de Heer A. Deruyttere uit.

De Klasse neemt een minuut stilte waar ter nagedachtenis van de overleden Confrater.

De tekst van deze lofrede zal in de *Mededelingen der Zittingen* verschijnen.

Benoemingen

Bij koninklijk besluit van 26 maart 2005 werd de Heer J. Berlamont tot werkend lid benoemd.

Bij ministerieel besluit van 21 maart 2005 werd de Heer A. Gioda tot corresponderend lid benoemd.

„Avenir de l'agriculture en Afrique de l'Ouest: le rôle des productions animales dans la partie centrale du Sénégal"

De Heer A. Buldgen stelt een mededeling voor getiteld als hierboven.

De HH. H. Paelinck, J.-J. Droesbeke, P. De Meester, R. Branckaert, R. Sokal en R. Leenaerts nemen aan de bespreking deel.

De Klasse beslist de tekst in de *Mededelingen der Zittingen* te publiceren.

Le séisme géant de subduction de Sumatra-Andaman du 26 décembre 2004: leçons pour une alerte efficace des tsunamis

M. T. Camelbeeck a présenté cette communication lors de la séance commune du 19 avril 2005.

La Classe désigne le deuxième rapporteur.

Concours 2005

Deux travaux ont été introduits régulièrement en réponse à la cinquième question du Concours 2005, intitulée: «On demande une étude sur l'application des Systèmes d'Information Géographique à la cartographie et à la modélisation du phénomène d'érosion des sols en région tropicale», à savoir:

Dino Moscoso, A. (s. d.) Identification of Erosion-prone Areas in the Province of Aklan Using Geographic Information. — School of Technology U. P. in the Visayas, 23 pp.

Heyvaert, V. (s. d.) Mapping and Modelling of Soil Erosion with GIS: Applicability of Different Erosion Models. Case Study: Chachoengcao Province, Thailand. — Vrije Universiteit Brussel, 95 pp. + 42 pp. (atlas).

Après avoir entendu les rapports de MM. C. De Meyer, A. Ozer et J. Poesen, la Classe décide de n'attribuer ni prix, ni mention honorable à ces travaux.

La séance est levée à 16 h 15.

„Le séisme géant de subduction de Sumatra-Andaman du 26 décembre 2004: leçons pour une alerte efficace des tsunamis"

De Heer T. Camelbeeck stelde deze mededeling voor tijdens de gemeenschappelijke zitting van 19 april 2005.

De Klasse duidt de tweede verslaggever aan.

Wedstrijd 2005

Twee werken werden regelmatig ingediend in antwoord op de vijfde vraag van de Wedstrijd 2005: „Men vraagt een studie van de toepassing van Geografische Informatie Systemen op de cartografie en de modellering van bodemerosie in tropische gebieden", namelijk:

DINO MOSCOSO, A. (z. d.) Identification of Erosion-prone Areas in the Province of Aklan Using Geographic Information. — School of Technology U. P. in the Visayas, 23 blz.

HEYVAERT, V. (z. d.) Mapping and Modelling of Soil Erosion with GIS: Applicability of Different Erosion Models. Case Study: Chachoengcao Province, Thailand. — Vrije Universiteit Brussel, 95 blz. + 42 blz. (atlas).

Na de verslagen van de HH. Ch. De Meyer, A. Ozer en J. Poesen gehoord te hebben, beslist de Klasse noch een prijs noch een eervolle vermelding aan deze werken toe te kennen.

De zitting wordt om 16 u. 15 geheven.

TABLE DES MATIERES — INHOUDSTAFEL

Communications scientifiques
Wetenschappelijke mededelingen

Classe des Sciences morales et politiques / Klasse voor Morele en Politieke Wetenschappen:

P. Raymaekers. — L'origine romaine des fers à esclaves marocains 217

D. Huyge. — The Fish Hunters of El-Hosh: Rock Art Research and Archaeological Investigations in Upper Egypt (1998-2004) 231

Classe des Sciences naturelles et médicales / Klasse voor Natuur- en Geneeskundige Wetenschappen:

T. Camelbeeck. — Le séisme géant de subduction de Sumatra-Andaman du 26 décembre 2004: leçons pour une alerte efficace des tsunamis 253

P. Janssens *et al.* — Buruli Ulcer: An Historical Overview with Updating to 2005 265

Classe des Sciences techniques / Klasse voor Technische Wetenschappen:

J.-J. Claustriaux. — La statistique dans les pays en développement: regard et perspective 303

G. Demaree *et al.* — Addendum to the paper "On the Amount of Rain Fallen in Macau, China, in the Year 1780" 313

J. Hus. — Environmental and Palaeoclimatic Significance of the Magnetic Signal in Lœss-Palaeosol Sequences 317

Eloge — Lofrede

Pierre Salmon 347

Procès-verbaux — Notulen

Classe des Sciences morales et politiques / Klasse voor Morele en Politieke Wetenschappen:

Séance du 19 avril 2005 / Zitting van 19 april 2005 ..... 352; 353

Séance du 17 mai 2005 / Zitting van 17 mei 2005 ..... 356; 357

Classe des Sciences naturelles et médicales / Klasse voor Natuur- en Geneeskundige Wetenschappen:

Séance du 19 avril 2005 / Zitting van 19 april 2005 ..... 352; 353

Séance du 24 mai 2005 / Zitting van 24 mei 2005 ..... 360; 361

Classe des Sciences techniques / Klasse voor Technische Wetenschappen:

Séance du 19 avril 2005 / Zitting van 19 april 2005 ..... 352; 353

Séance du 26 mai 2005 / Zitting van 26 mei 2005 ..... 366; 367

CONTENTS

Scientific Papers

Section of Moral and Political Sciences:
P. Raymaekers. — The Moroccan Slave Fetters' Roman Origin 217
D. Huyge. — The Fish Hunters of El-Hosh: Rock Art Research and Archaeological Investigations in Upper Egypt (1998-2004) 231

Section of Natural and Medical Sciences:
T. Camelbeeck. — The December 26, 2004 Sumatra-Andaman Megathrust Earthquake: Lessons for a Tsunami Warning System 253
P. Janssens *et al.* — Buruli Ulcer: An Historical Overview with Updating to 2005 265

Section of Technical Sciences:
J.-J. Claustriaux. — Statistics in Developing Countries: View and Tendency 303
G. Demaree *et al.* — Addendum to the paper "On the Amount of Rain Fallen in Macau, China, in the Year 1780" 313
J. Hus. — Environmental and Palaeoclimatic Significance of the Magnetic Signal in Lœss-Palaeosol Sequences 317

Biographical Sketch of a Deceased Member

Pierre Salmon 347

Minutes

Section of Moral and Political Sciences:
Meeting held on 19 April 2005 352
Meeting held on 17 May 2005 356

Section of Natural and Medical Sciences:
Meeting held on 19 April 2005 352
Meeting held on 24 May 2005 360

Section of Technical Sciences:
Meeting held on 19 April 2005 352
Meeting held on 26 May 2005 366

UNIVERSA B.V.B.A., Wetteren