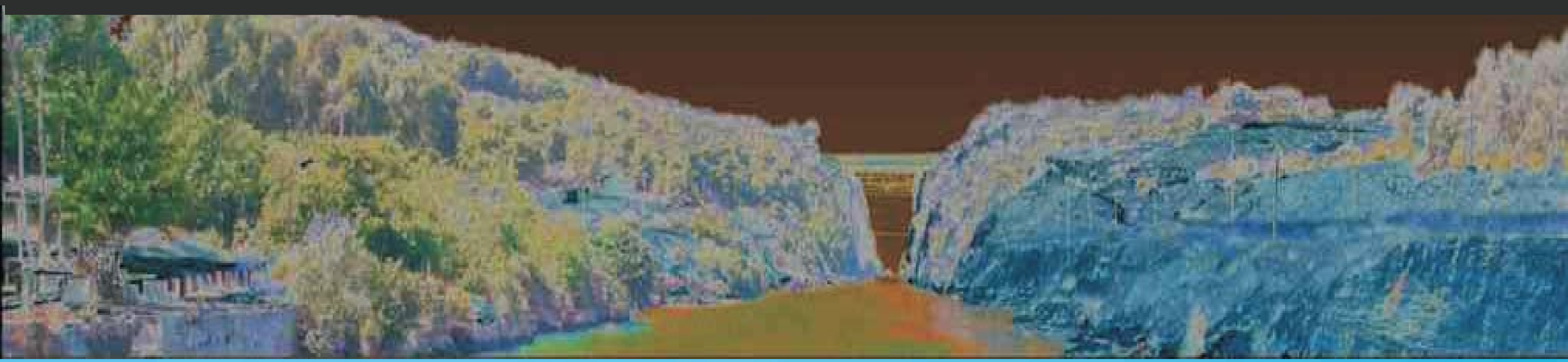
Proceedings Volume 2, 2011

Earthquake Geology and Archaeology: Science, Society and Critical Facilities



Editors

*C. Grützner, R. Pérez-López, T. Fernández Steeger, I. Papanikolaou
K. Reicherter, P.G. Silva, and A. Vött*

PROCEEDINGS
2nd INQUA-IGCP 567 International Workshop on Active Tectonics, Earthquake Geology, Archaeology and Engineering

19-24 September 2011
Corinth (Greece)

ISBN: 978-960-466-093-3

Proceedings

Earthquake Geology and Archaeology: Science, Society and Critical facilities

2nd INQUA-IGCP 567 International Workshop on Active Tectonics, Earthquake Geology, Archaeology and Engineering

Editors

C. Grützner, R. Pérez-López, T. Fernández-Steeger, I. Papanikolaou
K. Reicherter, P.G. Silva and A. Vött

Focus Area on Paleoseismology and Active Tectonics
INQUA

IUGS UNESCO IGCP 567
Earthquake Archaeology
Archaeoseismology along the Alpine-Himalayan seismic zone

This **Volume of Proceedings** has been produced for the **2nd INQUA-IGCP 567 International Workshop on Active Tectonics, Earthquake Geology, Archaeology and Engineering** held in Corinth (Greece), 19-24 September 2011. The event has been organized jointly by the INQUA-TERPRO Focus Area on Paleoseismology and Active Tectonics and the IGCP-567: Earthquake Archaeology.

This scientific meeting has been supported by the INQUA-TERPRO #0418 Project (2008-2011), the IGCP 567 Project, the Earthquake Planning and Protection Organization of Greece (EPPO – ΟΑΣΠ)

UCL | Aon Benfield UCL Hazard Centre | Birkbeck University of London | RWTH Aachen University

Ο.Α.Σ.Π. | JGU Johannes Gutenberg Universität Mainz | National & Kapodistrian University of Athens | Universidad de Salamanca | AEQUA

Instituto Geológico y Minero de España | GSSI | paleoseismicity.org

Printed by
The Natural Hazards Laboratory,
National and Kapodistrian University of Athens

Edited by
INQUA-TERPRO Focus Area on
Paleoseismology and Active Tectonics
& IGCP-567 Earthquake Archaeology

INQUA-IGCP 567 Proceedings, Vol.2

I.S.B.N. 978-960-466-093-3
PRINTED IN GREECE

paleoseismicity.org

Vol. 2: Earthquake Geology and Archaeology: Science, Society and Critical facilities (C. Grützner, R. Pérez-López, T. Fernández-Steeger,, I. Papanikolaou, K. Reicherter, P.G. Silva & A. Vött, Eds.). ISBN 978-960-466-093-3. Printed in Greece, 2011. 2nd INQUA-IGCP 567 International Workshop, Corinth (Greece).

Vol. 1: Archaeoseismology and Palaeoseismology in the Alpine-Himalayan collisional Zone (R. Pérez-López, C. Grützner, J. Lario, K. Reicherter & P.G. Silva, Eds.). ISBN 978-84-7484-217-3. Printed in Spain, 2009. 1st INQUA-IGCP 567 International Workshop. *Baelo Claudia*, Cádiz (Spain).

Preface.

After the very successful 1st Workshop on Earthquake Archaeology and Paleoseismology held in the ancient roman site of Baelo Claudia (Spain, 2009), the INQUA Focus Group on Paleoseismology and Active Tectonics decided to elaborate a bi-annual calendar to support this joint initiative with the IGCP-567 "Earthquake Archaeology". This second joint meeting moved to the eastern Mediterranean, a tectonically active setting within the Africa-Eurasia collision zone and located in the origins of the pioneer's works on archaeoseismology. However, for the coming year 2012, at least a part of us will move also to the New World, where the 3rd INQUA-IGCP 567 international workshop will take place in Morelia, Mexico in November 2012. It is planned to proceed with the meeting, so we are thinking of Aachen, Germany, to be the host in 2013, possibly together with Louvain, Belgium.

The aim of this joint meeting is to stimulate the already emerging comparative discussion among Earthquake Environmental Effects (EEE) and Earthquake Archaeoseismological Effects (EAE) in order to elaborate comprehensive classifications for future cataloguing and parametrization of ancient earthquakes and palaeoearthquakes. One of the final goals our collaborative workshops is the integration of archaeoseismological data in Macroseismic Scales such as the Environmental Seismic Intensity Scale ESI-2007 developed within the frame of the International Union for Quaternary Research (INQUA). In this second workshop we offer again a multidisciplinary and cross-disciplinary approach and program, since there is an urgent necessity to share the knowledge and objectives among geologists, seismologists, geodesists, archaeologists and civil engineers in order to improve seismic hazard assessments and analyses in a near future. Also, we intend to sharpen geoscientists and their research more in the direction of critical facilities, which are of world-wide public and political interest after the dramatic catastroph in Fukushima, Japan.

The last two years provided significant dreadful earthquake scenarios, which were in most of the cases oversized in relation to the data provided by the historical and instrumental seismicity. The Haiti Mw 7.0 (Haiti, Jan 2010), Malua Mw 8.8 (Chile, May 2010), Christchurch Mw 6.3 (New Zealand, Feb 2011), Tohoku Mw 9.0 (Japan, Mar 2011) and Lorca Mw 5.1 (Spain, May 2011) events illustrates that both extreme subduction earthquakes or moderate events can generate severe damage in relation to relevant secondary coseismic effects or Earthquake Environmental Effects (EEE). Most of these recent events have clearly demonstrated that the vibratory ground shaking is not the unique, or even most significant, source of direct damage, and it is by no means the only parameter that should be considered in seismic hazard assessments. The lessons offered by the aforementioned events corroborate once again the relevance of liquefaction, tsunamis, rockfalls, landslides, ground subsidence, uplift or failure as a major source of hazard. But this also underpins the need of re-evaluating the significance of macroseismic intensity as an empirical measurement of earthquake size. In fact, as highlighted in the last volume produced by the INQUA Focus Area (Serva et al., 2011), intensity is a parameter able to describe a complete earthquake scenario, based on direct field observation and suitable to be preserved in the geological, geomorphological and archaeological records.

With this aim the INQUA TERPRO #0418 Project (2008-2011) has implemented a world-wide online EEE Catalogue based on Google Earth in order to promote the use of the ESI-2007 Scale for seismic hazard purposes www.eeecatalog.sinanet.apat.it/terremoti/index.php. On the other hand the IGCP-567 is promoting an interesting shared approach of EEE data and EAE data for the same purpose. Examples of this variety of original research coming from this collaborative approach are the Geological Society of London Special Volume 316 (2009) ***Paleoseismology: Historical and Prehistorical records of Earthquake Ground Effects for Seismic Hazard Assessment*** (K. Reicherter, A.M. Michetti & P.G. Silva, Eds.), the Geological Society of America Special Papers 471, ***Ancient Earthquakes*** (2010) (M. Sintubin, I.S. Stewart, T. Niemi & E. Altunel, Eds.) and the Special Volume of Quaternary International (2011) ***Earthquake Archaeology and Paleoseismology*** (P.G. Silva, M. Sintubin & K. Reicherter, Eds.). In the same way, this abstract volume contains more than 80 contributions from researchers of more than 27 different countries and illustrates the upgrading shared knowledge on palaeo-, ancient, historical and instrumental earthquakes and images an impressive growth of our community. Our workshop was co-ordinated through the newly established website www.paleoseismicity.org, where earthquake info and blogs are openly shared.

Finally, we wish all participants a fruitful conference and workshop in the vicinity of the ancient sites of the Classical Greece around the Corinth Gulf, where earthquake science, wonderful landscapes, ancient cultures, amazing sunny days, fantastic "Greek cooking", nice beaches, daily cool beers, wine tasting events and late night gin tonics mixed with hot discussions are waiting for all of us. A special **"efharisto poli"** goes to Christoph Grützner and Raul Pérez-López for their invaluable work with the organisation and the abstract handling.

The Organizers of the 2nd INQUA-IGCP 567 Workshop
Ioannis, Klaus, Andreas and Pablo (Corinth, Sept. 2011)

ARCHAEOSEISMOLOGY OF THE AD 1545 EARTHQUAKE IN CHIANG MAI, NORTHERN THAILAND

Kázmér, M. (1), Kamol Sanittham (2), Punya Charusiri (3), Santi Pailoplee (3)

(1) Department of Palaeontology, Eötvös University, Pázmány sétány 1/c, Hungary. Email: mkazmer@gmail.com
(2). Department of Mathematics and Statistics, Chiangmai Rajabhat University, Chiang Mai, Thailand
(3) Department of Geology, Chulalongkorn University, Bangkok, Thailand

Abstract (Archaeoseismology of the A.D. 1545 earthquake in Chiang Mai, northern Thailand): *The A.D. 1545 Chiang Mai earthquake in northern Thailand was studied by historical and archaeological sources.The temple Wat Chedi Luang has lost about half of the original 80-metres height due to southward-directed collapse. Twenty-one temple sites – out of 74 visited – has tilted pagodas, up to 5° in various directions, dominated by a SE trend. All damaged temples were built before the 1545 earthquake. We suggest that a city-wide liquefaction event caused tilting. The responsible earthquake possibly occurred along the Doi Suthep Fault within city limits. Possible activity of distant faults is assessed.*

Key words*: palaeoseismology, Thailand, liquefaction, Wat Chedi Luang*

INTRODUCTION

An important obstacle to the assessment of earthquake hazard at present is the lack of information about old earthquakes (Ambraseys, 2009: xii). The locations of larger historical earthquakes have been found to be known well enough to guide field studies for further in situ investigations. Properly run field studies provide reliable observations for the assessment of damage, intensity, and its distribution, ground effects and surface faulting. Field studies of old earthquakes are time-consuming and often present subtle problems but they are essential (Ambraseys 2009: 16). Here we provide a brief description of traces of a significant earthquake in Northern Thailand, and provide assessment of seismic parameters of the event.

Fig. 1: Wat Chedi Luang in Chiang Mai, Thailand, seen from the southeast. Damaged during the AD 1546 earthquake, the upper half of the stupa fell to the south.

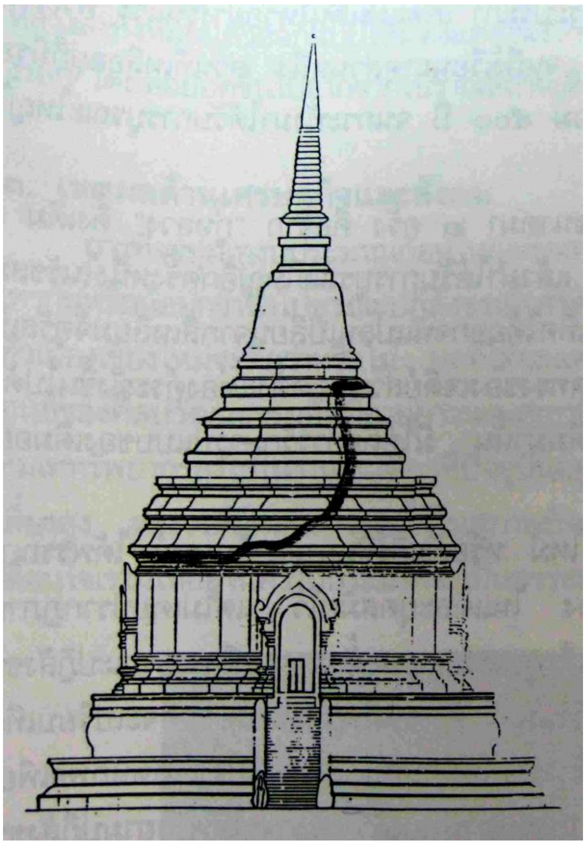


Fig. 2: Archaeological reconstruction of the pre-earthquake dimensions of Wat Chedi Luang as seen from the east. Total height was approx. 80 m. The portion above the heavy line is the art historian's vision about its looks.

Both historical documents and archaeological data are available describing the A.D. 1545 earthquake in Northern Thailand. We studied the Buddhist temples in and around the old city of Chiang Mai (Kázmér &

Sanittham, 2011) to identify possible earthquake-induced damages preserved in the buildings' structure and orientation.

Currenty earthquake activity in northern Thailand is interpreted within the framework of Thoen Fault (Chiang Saen, May 2007, M_L = 6.3), Mae Tha and Pha Youv fault zones tens of kilometres away (Pailoplee et al., 2010). Since recurrence time of major earthquakes seems to be longer than the instrumental period of 50 years, archaeoseismology is a necessary tool to extend the observation period to centuries.

METHODS

Historical, archaeological, and geological-geophysical data are combined to understand the Chiang Mai earthquake of AD 1545. The published historical description was cross-checked with archaeological data of the site of Wat Chedi Luang and elsewhere. We visited 74 temples of Chiang Mai city. While recording earthquake archaeological effects (Rodriguez-Pascua et al. 2011), we measured the angle and direction of tilt of the chedi (stupa) by a stonemason's tiltmeter and a compass, respectively.

Coordinates of chedi location were taken from the digital map of Northern Thailland (ThinkNet 2010). Construction ages were drawn from Thai-language publications. When no printed source was available, we accepted the dating of tourist information tablets in the monasteries.

There is no official English transliteration system for the Thai language. English spelling of Thai names is inconsistent to the extent that one's own name is written differently on subsequent occasions. In this paper we use names as found on the electronic map of ThinkNet (2010), which is neither official, nor better than any other spelling.

HISTORICAL DATA

There was a damaging earthquake in Chiang Mai city (Northern Thailand) on 28 July 1545 in the afternoon hours between 4.30 and 6.00 pm. *„The earth trembled and shook, groaned and moaned, very intensely. The finials,* (top parts) *yòt, of the Jedi Luang and of the jedi in Wat Phra Sing broke off and fell down, and also the finials of many other jedis"*, recorded the contemporary Chiang Mai Chronicle in Lanna language (translated by Penth, 2006).

WAT CHEDI LUANG IN CHIANG MAI

The largest chedi (stupa, pagoda) ever built in what is Thailand today is the Wat Chedi Luang, standing in the monastery of the same name in the centre of old Chiang Mai city (Fig. 1). Built in 1391, it has been reconstructed and enlarged several times, A huge chedi, 56 x 56 m rectangular basement, approx. 80 m high was built in 1479-1481. The base was enlarged and strengthened in 1512 (Podjarawaraporn, 2547).

On 28 July 1545 there was a huge rainstorm and an earthquake, which caused the chedi to topple, leaving only half if its structure to stand (Fig. 2). The power and richness of the Medieval Lanna Empire already in the decline, no funds have ever been available to restore the damaged building to its former glory. The chedi was left in this damaged condition for more than four centuries. A cosmetic restoration in 1992 completed the strengthening by a 60 x 60 m base, .

TILTED BUILDINGS CITYWIDE

In addition to the famous damaged chedi, numerous religious and secular monuments in and around the old city bear evidence for some kind of earthquake damage. The most obvious evidence is tilting of chedis: the pointed top part of the monument clearly deviates from the vertical by a few degrees (Fig. 3). (The lightweight metal decoration at the very top is almost always heavily tilted; we did not take these into account, only the brick portion below.) Historical data on construction time of the chedis indicate that all of them were built in the 14-15th century AD, before the A.D. 1545 earthquake (Fig. 4). Locations and tilt directions are mapped on Fig. 5.

Tilt directions are dominated by a conspicuous SE trend (Fig. 6).

Fig. 3: Tilted buildings citywide

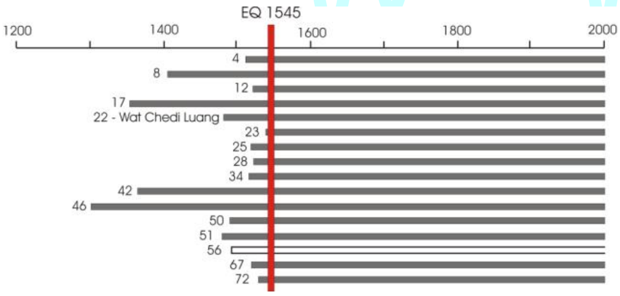


Fig. 4: All tilted chedis (stupas) were built before the AD 1545 earthquake. 4 – Wat Chiang Yeun, 8 – Wat Hua Khuang, 12 – Wat Lok Mo Li, 17 – Wat Phra SIngh, 23 – Wat Chai Prakiat, 28 – Wat Phuak Hong, 34 – Wat Chet Rim, 42 – Wat Umong, 46 – Wat Chiang Man, 50 – Wat Srisupan, 51 – Wat Nantharam, 56 – Wat Daowadueng (no tilting was observed), 67 – Wat Bupharam, 72 – Wat Chomphu.

SUBSOIL

The tilted chedis are all on the alluvial plain of the Ping River, extending over at least 4 km^2. Groundwater lever was high during our survey in August 2010, about 70 to 100 cm below ground, as seen in several wells within the temple compounds. Historical data indicate a rainy summer season for 1545, too.

We suggest that a city-wide liquefaction event, caused uneven settlement and subsidence of the buildings in the saturated soil. The dominant SE-ward tilt direction possibly reflects strong motion directionality.

INTENSITY

While modified Mercalli intensity VII is the damage threshold for many archaeological sites (Kovach and Nur, 2006), we assume that damages to Wat Chedi Luang related to the 1545 earthquake require a larger intensity due to the especially compact construction of the building. The pagoda, built like a pyramid, is certainly a more earthquake-resistant structure than any ordinary city house, even palace. Intensity IX or higher (good masonry damaged seriously, in areas of loose sediment, sand, mud, and water ejected – Rapp, 1986) seems more probable.

Intensity VIII to IX (heavily damaging to destructive) is assumed on the ESI 2007 environmental intensity scale (Michetti et al., 2007): liquefaction with settlement up to 30 cm or more. The total affected area was in the order of 1000 to 5000 km^2 (Reicherter et al., 2009), i.e. all of the Chiang Mai-Lamphun Basin.

EPICENTER AND MAGNITUDE

Known and possibly active faults were assessed for source of the earthquake, and the minimum magnitude for liquefaction calculated after Obermeier (1996, Fig. 42).

The Doi Suthep fault, the master fault of the half-graben of the Chiang Mai Basin is 3 km away. It is not known to be active: a minimum M 5.5 seismic event here could cause liquefaction.

The SW-NE trending, left-lateral Mae Kuang Fault 32 km to the NE is possibly inactive since the Tertiary, althought the fault trace is particularly conspicuous in the landscape (Rhodes et al. 2004). A minimum M 6.3 seismic even would have been sufficient to cause liquefaction in Chiang Mai.

The Lampang-Thoen fault zone 120 km to the SE is active (Chiang Saen, May 2007, M_L = 6.3). The segments are long enough to produce M 7 earthquakes (Pailoplee et al., 2009). A minimum M 7 seismic event is needed to cause liquefaction in Chiang Mai city.

The Sagaing Fault in Myanmar, forming the boundary between the Sunda and Burma plates is 200 km to the W. It regularly produces M > 7 earthquakes (M 7.0-7.4) (Hurukawa & Maung, 2011). However, the M 7.5 earthquake on December 3, 1930, did not cause any liquefaction event in Chiang Mai we are aware of. A lack of proper attenuation model for Thailand (Chintanapakdee et al., 2008) prevents formulating a suitable explanation. There is local model developed for Chiang Mai (Kannika & Takada, 2009), although for rock sites, not for alluvium. We suggest that earthquake intensities display a strong directionality along the right-lateral Sagaing Fault: higher intensities occurring parallel and lower intensities perpendicular to the fault, thus protecting Chiang Mai from major plate-boundary events.

Whether any of the above or another fault is resonsible for the AD 1545 earthquake is an open question as yet. Studies on strong motion direction causing the major damages (see, for example. Korjenkov & Mazor, 1999, 2003; Kázmér & Major, 2010; Hinzen, 2008, 2009) may help tor resolve some of the open questions.

Acknowledgements: Our thanks are due to the staff of Mahamakat Buddhist University, Lanna Campus library for their help in accessing relevant literature in the Thai language. Financial help from Hungarian National Science Foundation (OTKA) grant K 67.583 and and an IGCP 567 travel grant are sincerely acknowledged here. Raúl Pérez López is thanked for his comments, which improved this manuscript.

References

Publication dates of Thai-published books in Thai only are given as of the Thai calendar. Deduce 543 for conversion to western, Gregorian years.

Ambraseys, N.N. (2009). *Earthquakes in the Mediterranean and Middle East. A Multidisciplinary Study of Seismicity up to 1900.* Cambridge, Cambridge University Press. 968 p.

Chintanapakdee, C., Naguit, M.E. & Charoenyuth, M. (2008). Suitable attenuation model for Thailand. – *14th World Conference on Earthquake Engineering:*

Innovation Practice Safety, Beijing, 2008**.** [8 p.] Download: http://www.14wcee.org/Proceedings/files/02-0088.PDF (accessed 25 June 2011)

Hinzen, K.-G. (2008). Can ruins indicate a back azimuth?: *Seismological Research Letters*, 79 (2), 290.

Hinzen, K.-G. (2009). Simulation of toppling columns in archaeoseismology. *Bulletin of the Seismological Society of America* 99 (5), 2855–2875.

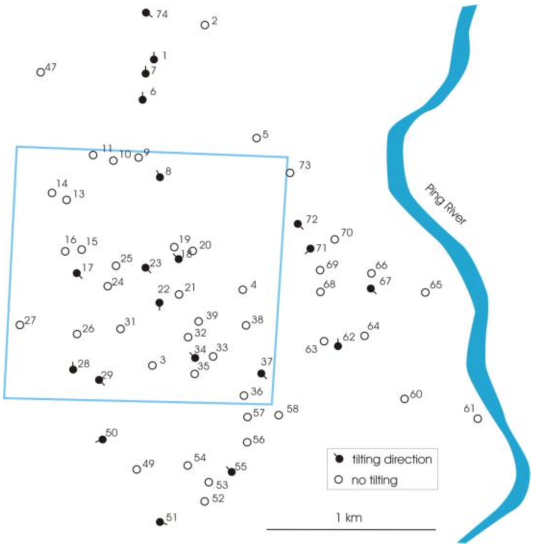


Fig. 5: Tilted chedis (Fig. 4) (black dots) on the alluvial plain of Ping River (Margane & Tatong, 1999). Ticks towards direction of tilting. Untilted chedis are marked with empty circles. Rectangle indicates walled city of old Chiang Mai.

Hurukawa, N. & Maung, P.M. (2011). Two seismic gaps on the Sagaing Fault, Myanmar, derived from relocation of historical earthquakes since 1918. – *Geophysical Research Letters* 38, L01310, 5 PP., doi:10.1029/2010GL046099

Kannika, P. & Takada, T. (2009). *Updating framework for site-specific attenuation relation of seismic ground motion in Thailand.* MSc thesis, Building Research Institute, Tsukuba, Japan, 70 p.

Kázmér, M., & Major, B. (2010). Distinguishing damages of two earthquakes – archeoseismology of a Crusader castle (Al-Marqab citadel, Syria). In: *Ancient Earthquakes*. (Stewart, I., Sintubin, M., Niemi, T., Altunel, E. eds). Geological Society of America Special Paper, 471, 186 –199.

Kázmér, M. & Sanittham, K. (2011). Archeoseismology of the A.D. 1545 earthquake in Chiang Mai, northern Thailand. In: *International Symposium on the 2001 Bhuj Earthquake and Advances in Earthquake Science*, AES 2011. 22-24 January 2011, Institute of Seismological Research, Raisan, Gandhinagar, India. Abstract Volume AES 2011, 117-118.

Korjenkov, A.M. & Mazor, E. (1999). Seismogenic origin of the ancient Avdat Ruins, Negev Desert, Israel. *Natural Hazards* 18, 193–226.

Korjenkov, A.M. c Mazor, E. (2003). Archaeoseismology in Mamshit (southern Israel): Cracking a millennia-old code of earthquakes preserved in ancient ruins: *Archäologischer Anzeiger*, 2003 (2), 51–82.

Kovach, R.L & Nur, A. (2006). Earthquakes and archeology: Neocatastrophism or science?: *Eos, Transactions, American Geophysical Union* 87 (32), 317.

Margane, A. & Tatong, T. (1999): Aspects of the hydrogeology of the Chiang Mai-Lamphun Basin, Thailand that are important for the groundwater management. – *Zeitschrift für angewandte Geologie* 45, 188-197.

Michetti, A.M., Esposito, E. et al. (2007). Environmental Seismic Intensity Scale 2007 – ESI 2007. In: Vittori, E:, Guerreri, L. eds. *Memorie Descrittive della Carta Geologica d'Italia.* LXXIV. Servizio Geologico d'Italia, Roma, 7–54.

Obermeier, S.F. (1996): Use of liquefaction-induced features for paleoseismic analysis. – *Engineering Geology* 44, 1-76.

Pailoplee, S., Takashima, I., Kosuwan, S. & Charusiri, P. (2009). Earthquake activities along the Lampang-Theon fault zone, northern Thailand: evidence from paleoseismological and seismicity data. – *Journal of Applied Science Research* 5 (2), 168-180.

Pailoplee, S., Sugiyama, Y. & Charusiri, P. (2010). Probabilistic seismic hazard analysis in Thailand and adjacent areas by using regional seismic source zones. – *Terestrial, Atmospheric and Ocean Sciences* 21, 757–766.

Penth, H. (2006). Earthquakes in Old Lan Na: part of natural catastrophes. *Chiang Mai University CMU Journal* 5 (2), 255-265.

Podjarawaraporn (2547). *Pra wad Wat Chedi Luang wor ra wi harn.* [History of Wat Chedi Luang.] Text by Pra Bhuda Podjanawaraporn (Chan Kusato), pictures by Pra Kro Soponkaweewat (Thanachan Suramanee). Published by Wat Chedi Luang, Chiang Mai, Thailand, 160 p. ISBN 974-92159-8-2 (In Thai)

Rapp, G., Jr. (1986). Assessing archaeological evidence for seismic catastrophes. *Geoarchaeology* 1, 365–379.

Reicherter, K., Michetti, A.M. & Silva Barroso P.G. (2009). Palaeoseismology: historical and prehistorical records of earthquake ground effects for seismic hazard assessment. *Geological Society, London, Special Publication* 316, 1-10.

Rhodes, B.P., Perez, R., Lamjuan, A. & S. Kosuwan, S. (2004). Kinematics and tectonic implications of the Mae Kuang Fault, northern Thailand. *Journal of Asian Earth Sciences* 24 (1): 79-89.

Rodríguez-Pascua M.A., R. Pérez-López, J.L. Giner-Robles, P.G. Silva, V.H. Garduño-Monroy and K. Reicherter (2011). A Comprehensive Classification of Earthquake Archaeological Effects (EAE) in Archaeoseismology: application to ancient remains of Roman and Mexican cultures. *Quaternary International.* DOI: 10.1016/j.quaint.2011.04.044.

ThinkNet (2010). *Map of 14 northern provinces of Thailand* + CD. Bilingual Mapping Software. ThinkNet Co., Ltd, Bangkok, Thailand. (In Thai and English)

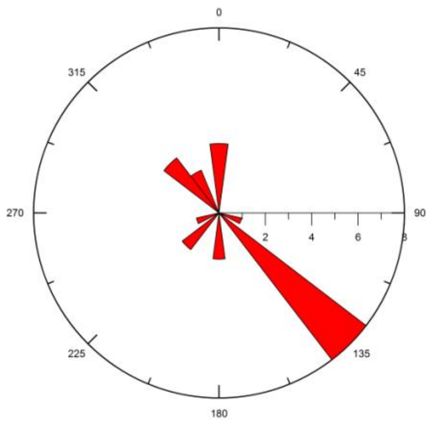


Fig. 6:Tilt directions plotted in polar bar chart. Horizontal axis – number of pagodas tilted in a certain direction. Note the prominent southeastward tilting of several chedis.

Index

Proceedings

INQUA - IGCP 567 CORINTH (GREECE), 2011

RWTH AACHEN UNIVERSITY Neotektonik Georisiken

ΕΘΝΙΚΟ & ΚΑΠΟΔΙΣΤΡΙΑΚΟ ΠΑΝΕΠΙΣΤΗΜΙΟ ΑΘΗΝΩΝ – NATIONAL & KAPODISTRIAN UNIVERSITY OF ATHENS – LABORATORY OF NATURAL HAZARDS PREVENTION & MANAGEMENT

Ο.Α.Σ.Π.

UCL

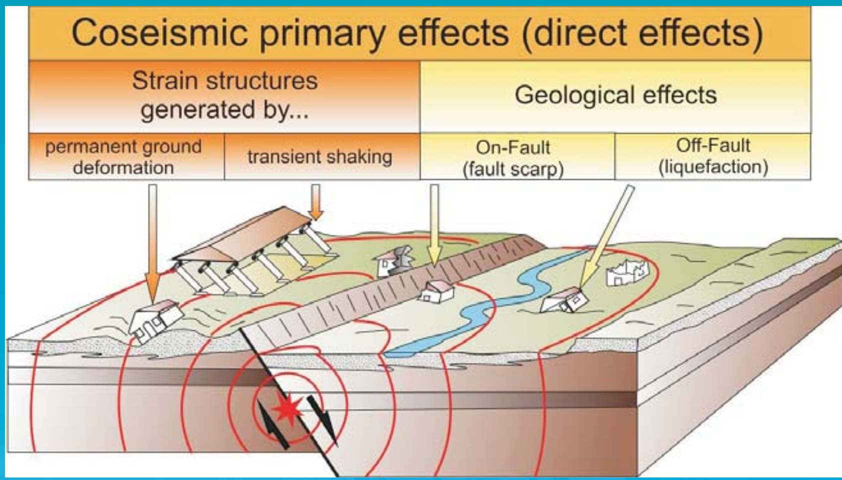
Aon Benfield UCL Hazard Centre

JG|U JOHANNES GUTENBERG UNIVERSITÄT MAINZ

VNiVERSiDAD D SALAMANCA

AEQUA

GSSI



EARTHQUAKE ARCHAEOLOGICAL EFFECTS (EAE)	I. PRIMARY EFFECTS (DIRECT EFFECTS)	GEOLOGICAL EFFECTS	*On-fault geological effects*	- Fault scarps - Seismic Uplift / subsidence
			Off-fault geological effects	- Liquefactions and dike injections - Landslides - Rock fall - Tsunamis/Seiches - Collapses in caves - Folded mortar pavements - Fractures, folds & pop-ups on *regular pavements* - Fractures, folds & pop-ups on *irregular pavements*
		BUILDING FABRIC EFFECTS	*Strain structures generated by permanent ground deformation*	- shock breakouts in flagstones - Rotated and displaced buttress walls - Tilted walls - Displaced walls - Folded walls
			Strain structures generated by transient shaking	- Penetrative fractures in masonry blocks - Conjugated fractures in walls made of either *stucco* or *bricks* - Fallen and oriented columns - Rotated and displaced masonry blocks in walls and drums in columns - Displaced masonry blocks - Dropped key stones in arches or lintels in windows and doors - Folded steps and kerbs - Collapsed walls (including human remains and items of value under the rubble) - Collapsed vaults - Impact block marks - Broken pottery found in fallen position - Dipping broken corners
	II. SECONDARY EFFECTS (INDIRECT EFFECTS)			- Fires - Repaired buildings - Recycling anomalous elements - Settlement abruptly abandoned - Stratigraphic gap in the archaeological record - Flash floods generated by collapses of natural and human dams - Anti-seismic buildings

M.A Rodríguez Pascua et al. (2011). Quaternary International Sp. Vol. on Earthquake Archaeology and Paleoseismology (P.G. Silva, M. Sintubin & K. Reicherter Eds.)

MINISTERIO DE CIENCIA E INNOVACIÓN

Instituto Geológico y Minero de España

INQUA TERPRO Paleoseismology and Active Tectonics

ESI-2007

IUGS UNESCO IGCP 567

paleoseismicity.org