Earth Consultants International

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Dr. Yeats has worked since 1971 in earthquake geology, focusing on the three-dimensional investigations of active faults and folds using oil-industry borehole and seismic data, including data from producing oil fields. With his students, he has completed investigations on the Red Mountain, San Cayetano, Santa Susana, Simi, San Gabriel, and Oak Ridge faults in the Ventura basin in addition to fault systems in the Santa Barbara-Carpinteria area, the East Ventura basin, and the San Fernando Valley. In addition, he has completed studies in the northern and eastern Los Angeles basin. This has led to a new understanding of the source dimensions of the 1971 San Fernando, 1987 Whittier Narrows, and 1994 Northridge earthquakes. He has also completed three-dimensional studies of active structures in the Cuyama basin and has mapped on San Miguel, Santa Cruz, and San Nicolas islands in the California Continental Borderland. He curated a relatively complete set of well files (logs, histories, paleo, dipmeter, surveys) for the Ventura, Santa Barbara, Cuyama, and northern Los Angeles basins; most of these are in repositories at the campuses of two California State Universities (Bakersfield CSU Core Repository for Ventura and Santa Barbara basin files, and Long Beach for Los Angeles basin files).

Internationally, he was the first to map active faults in the Himalayan foreland fold-thrust belt of Pakistan and later assisted the government of India in a source characterization of the Himalayan plate-boundary megathrust, which has produced four earthquakes of M≥7.8 since 1897. He was part of a team that discovered the surface rupture accompanying the October 2005 M7.6 earthquake in Kashmir, northern Pakistan. He assisted the New Zealand Geological Survey in their study of active reverse faults in Central Otago as part of an evaluation of hydroelectric power potential of the South Island, including the Clyde Dam, and served as an advisor to the New Zealand government in planning its earth science programs. He also assisted the China Earthquake Administration in a source characterization of four historical earthquakes in Gansu Province and Inner Mongolia in western China. In 2002, he led an ECI team to study the March 2002 Nahrin, Afghanistan earthquake.

He has been a member of the Southern California Earthquake Center since its inception. He has been funded by the earthquake external grants program of the U.S. Geological Survey since the early 1970s and recently completed an evaluation of the source region of the Whittier Narrows earthquake and the earthquake potential of the San Gabriel Valley, the Whittier and Chino faults and the Coyote fold belt in the eastern Los Angeles basin. In 1994-1995, he served on a panel of the Office of Technology Assessment, U.S. Congress, evaluating the reauthorization of the National Earthquake Hazards Reduction Program (NEHRP).

In 1990, he was instrumental in establishing an offshore active tectonics group at Oregon State University. This group has identified nine active strike-slip faults at the Cascadia plate boundary with slip rates of 5-8 mm/yr and is now using late Pleistocene low-stand geomorphic features such as shorelines and river channels to work out slip rates of structures on the Oregon continental shelf. This group, led by his former student Chris Goldfinger, now associate professor in the OSU College of Oceanic and Atmospheric Sciences, pioneered the new field of

turbidite paleoseismology on the northern San Andreas fault and the Cascadia Subduction Zone.

Combining subsurface well and seismic data with surface mapping, his group constructed fault maps at 1:100,000 scale of the Willamette Valley, Oregon. More recently, he has been involved in consulting regarding the seismic and surface-rupture potential of the Southern Whidbey Island and Seattle faults in the Puget Sound region, and served on a seismic review team for a proposed nuclear waste treatment plant at Hanford in eastern Washington.

Also in 1990, he organized a task group in paleoseismology as part of the Inter-Union Commission on the Lithosphere. This group organized paleoseismology workshops in Marshall, California in September 1994, Erice, Italy in September 1995, Beijing, China in August 1996, and Dehra Dun, India, in March 1997. The Marshall workshop led to a special section of the Journal of Geophysical Research in March 1996, devoted to papers on paleoseismology.

EDUCATION

Ph.D. Geology, University of Washington	1958
B.A. Geography, University of Florida	1952

PROFESSIONAL REGISTRATIONS

Professional Geologist:	California, PG 1976
Professional Geologist:	Oregon, PG 177
Professional Geologist:	Washington, PG 998

PROFESSIONAL HISTORY

Senior Consultant, Earth Consultants International, Inc.	1997-Present
Professor of Geology, Oregon State University, Corvallis, Oregon	1977-1997
Chair, Department of Geology, Oregon State University	1977-1985
Associate Professor and Professor of Geology, Ohio University, Athens	1967-1977
Exploitation Engineer, Senior Production Geologist, Senior Staff Geologist. Shell Oil Company, Ventura and Los Angeles, California	1958-1967
Physicien Associé, Institut de Physique du Globe de Paris, France	1993
Visiting Scientist, Seismotectonics Research Section, Geological Survey of Japan, Tsukuba	1992
Visiting Scientist, New Zealand Geological Survey, (now Institute of Geological and Nuclear Sciences), Lower Hutt	1983-1984; 1999
Summer Intern, F.B. Leighton and Associates, La Habra, California	1971

PROFESSIONAL AFFILIATIONS

Geological Society of America (Fellow)

Chairman, Structural Geology and Tectonics Division	1984-1985
Chairman, Cordilleran Section	1988-1989
Cordilleran Section Annual Meeting Co-Chairman, 1980; Chairman 2002	
Associate Editor, GSA Bulletin	1987-1989
Richard H. Jahns Distinguished Lecturer in Engineering Geology (joint with Association of Engineering Geologists)	1995-1996

American Association for the Advancement of Science (Fellow)
Seismological Society of America
Earthquake Engineering Research Institute

American Association of Petroleum Geologists
Michel T. Halbouty Human Needs Award 1998
Outstanding Educator Award, Pacific Section 1991
Coast Geological Society President 1962-1963
American Geophysical Union

COMMITTEE MEMBERSHIPS

Southern California Earthquake Center
Office of Technology Assessment Panel, U.S. Congress, for the Reauthorization of the National Earthquake Hazard Reduction Program 1994-1995
Member of committee reviewing earth-science programs for the Department of Scientific and Industrial Research, New Zealand, prior to a reorganization of those programs 1989-1990
Inter-Union Commission on the Lithosphere
Chairman, Working Group 1, Recent Plate Movements and Deformation 1987-1990
Chairman, Task Group II-3, Paleoseismology of the Late Holocene 1990-1997
Member, Oregon State Board of Geologist Examiners 1981-1983
Member, Geophysics Study Committee, National Research Council 1987-1994
Member, U.S. Geodynamics Committee 1992-1994
Head of U.S. delegation to international conference on neotectonics of South Asia, Dehra Dun, India, 1986

SELECTED PROJECT EXPERIENCE

Pacific Northwest, USA

Senior Consultant, Brightwater Wastewater Treatment Plant near Woodinville, Washington. ECI was hired by Sno-King Environmental Alliance to review potential hazards to this plant. We found that the treatment plant proposed by King County lies within the newly discovered Southern Whidbey Island fault zone, and we recommended trenching the footprints of all surface facilities prior to permitting. We also assisted the City of Woodinville in developing its response to the proposed plant, including preparing a GIS layer to their planning documents locating aeromagnetic and LiDAR lineaments in the City and its urban growth boundary. Dr. Yeats also assisted the city of Woodinville in upgrading their local seismic ordinances.

Review Panel Member, Re-evaluation of Earthquake Hazards to Proposed Nuclear Waste-Treatment Plant at Hanford, Washington. Dr. Yeats, together with other experts, served as member of a review panel under contract to the U.S. Army Corps of Engineers through the URS Corporation that evaluated tectonic models leading to a seismic hazard assessment of the Yakima fold belt, where the proposed nuclear waste treatment plant would be located. The panel reviewed a previous analysis done in 1996 by Geomatrix and found (in 2006) that the hazard is higher than previously estimated, based on new information on seismicity and crustal strain. The apparent emphasis of the Geomatrix analysis on one blind structure, the Toppenish Ridge, is due to a recurrence interval measured in tens of thousands of years and the removal of pre-Holocene evidence by Missoula floods.

Senior Consultant, Seismic Hazard Review of Portland General Electric Dams in Northwestern Oregon. PGE undertook a vulnerability assessment of their hydroelectric dams in the Cascade Mountains, Coast Range and Willamette Valley in light of the new

findings regarding active crustal faults in Oregon. Under contract to Golder Associates, ECI provided seismic hazard data within 100 km of each of the PGE dams, and served as a peer reviewer of the final hazard analysis.

Senior Consultant, Harbor West Condominium Insurance Claim. A condominium built out over the water in West Seattle was heavily damaged in the 2001 Nisqually earthquake, and the insurance company denied its claim for compensation because of its conclusion that the damage was due to poor construction. Working with ECI's engineering seismologist, we determined that damage was concentrated at the site because of focusing of seismic waves from the slab earthquake along the Seattle fault. Even though the Seattle fault did not rupture, the highest damage occurred along an east-west line updip from the tip of the blind Seattle fault.

Principal Investigator, Active Tectonics of the Central Oregon Shelf. Multichannel seismic profiles, swath bathymetry, sidescan sonar, and submersible investigations led to the recognition of a blind thrust off Newport, Oregon capable of an earthquake as large as M6.7. An offshore anticline is crossed by a late Pleistocene low-stand stream channel that has been warped over its crest. Low-stand shoreline features including beach cliffs, sand bars, and estuaries cut Heceta, Coquille, and Nehalem Banks. These provide evidence of warped shoreline angles, indicating that the shelf is tectonically deformed in late Quaternary time, and that coastal and offshore crustal structures are earthquake hazards.

California

Senior Consultant, Seismic Hazard Review of the Castaic Dam Near the San Gabriel Fault in northern Los Angeles County. As part of the re-certification process for Castaic Dam, ECI provided Golder Associates with an accurate location of the San Gabriel fault near the dam, and an analysis of the slip rates, earthquake magnitudes and probabilities for the San Gabriel and Holser faults.

Senior Consultant, Mission Hills Fault Investigation. This study evaluated the nature of deformation along Balboa Boulevard on the southern flank of the Mission Hills in the San Fernando Valley, following severe damage of gas and water lines as a result of the 1994 Northridge earthquake. A review of oil-industry subsurface well data, multichannel seismic profiles, and surface geology and tectonic geomorphology led to a revised location of the Mission Hills reverse fault.

Senior Consultant, Investigation of Deformation in a Moorpark Development. ECI was consulted after the discovery of extensive deformation of Quaternary gravels in trench excavations in the proposed housing development, placing it in regulatory limbo. We evaluated the geological hazards from surface faulting and folding and determined that nearly all the deformation was older than 50,000 years. The deformation younger than 50,000 years was mapped, the geological hazard was mitigated by engineering design, and the project went forward.

Principal Investigator, Earthquake Hazards of the Northern and Eastern Los Angeles Deformed Zone. We mapped structures that extend through downtown Los Angeles west to Santa Monica and east to the Santa Ana River. These include the Wilshire arch with its axis along Wilshire Boulevard, the blind Las Cienegas reverse fault, the Hollywood pull-apart basin between the strike-slip Hollywood and Santa Monica faults, and the blind

thrusts generating the Montebello and Santa Fe Springs anticlines, the surface expression of the 1987 Whittier Narrows earthquake. The slip rate on the blind thrust generating the Coyote Hills anticline has been determined using dislocation modeling. An earthquake source model for the San Gabriel Basin, northern Puente Hills, and San Jose Hills has been published.

Principal Investigator, Earthquake Hazards of the San Fernando Valley and Santa Susana Mountains. We mapped active subsurface and surface structures that were reactivated during the 1971 and 1994 earthquakes. The 1971 surface rupture follows bedding on the south side of the Mission Hills-Merrick syncline and appears to be in large part a flexural-slip fault. The main 1971 fault is blind and within well depth is called the Northridge Hills thrust. This structure and the Mission Hills reverse fault merge eastward to the Verdugo active fault, which has not ruptured historically. The 1994 blind thrust was not recognized beforehand, but over time, this has uplifted the footwall of the Santa Susana thrust, and future blind thrusts of this type can now be recognized based on their geological signature. Terminations of both 1971 and 1994 aftershock zones correspond to geometric segment boundaries mapped in and adjacent to the Santa Susana Mountains. An analogous reverse-fault earthquake pair, the 1929 Murchison and 1968 Inangahua earthquakes in New Zealand, was analyzed for the New Zealand Institute of Geological and Nuclear Sciences.

Principal Investigator, Earthquake Hazards of the East Ventura Basin. Although much of the San Gabriel fault has been shown not to be active, the southeastern part of this fault in Santa Clarita has evidence of late Quaternary displacement. The Holser and Del Valle faults also show signs of activity.

Principal Investigator, Earthquake Hazards of the Western Ventura Basin and Santa Barbara-Carpinteria Area. The Oak Ridge, San Cayetano, and Red Mountain reverse faults are active, and the first two have demonstrated high slip rates, with earthquake recurrence intervals measured in hundreds of years. The absence of large historical earthquakes makes this region one of particular concern. A set of south-dipping reverse faults was mapped in the Carpinteria and Santa Barbara-Goleta regions using subsurface and surface data. The Santa Clara Valley is being deformed by flexural-slip faulting, which led to studies related to extension of a landfill northeast of Santa Paula.

Principal Investigator, Earthquake Hazards of the Cuyama basin. The southern end of the Salinian block was mapped from the Big Pine fault northwestward past the Morales Canyon oil field. The inactive Russell fault is overridden by the active Whiterock and Morales thrusts, which continue southeast into the Cuyama Badlands. These structures could move at the same time as the adjacent San Andreas fault, although there is no evidence they did so in the 1857 Fort Tejon earthquake of M_w 7.9.

Senior Consultant, Vintage Petroleum This oil company purchased a large number of oil fields in southern California, in areas where Dr. Yeats has done significant work. He was hired to review his work with their staff and conduct a field trip through the Ventura basin.

International

Senior Consultant, Investigation of Earthquake Effects in Nahrin, Afghanistan. Following an earthquake in 2002 where 1,200 people lost their lives, ECI did a damage

assessment of the meizoseismal region, determined isoseismals based on the MSK intensity scale (most appropriate for central Asia), and recommended relocations of destroyed villages based on the near-surface geology.

Senior Consultant, Seismic hazard Evaluation of the Yokosuka, Japan, Naval Base. Working with ECI's engineering seismologist, Dr. Yeats evaluated the potential earthquake sources within 50 km of the site based on geology, historical and instrumental seismicity, and crustal strain based on GPS. These sources included the Nankai and northern Japan subduction zones and several crustal faults.

Senior Consultant, Earthquake Hazards to Port Facilities in Karachi, Pakistan. We determined that the seismic hazard map of Pakistan greatly underestimates the hazard to Pakistan's largest city, with 14 million people, lying close to two major plate boundaries. Our analysis was based on surface geology, an active-fault inventory, and historical and instrumental seismicity.

Principal Investigator, Earthquake Hazards Evaluation of the Himalayan Megathrust, Northwest India. This study included field mapping of active structures, subsurface mapping of the Sub-Himalayan décollement using oil-industry borehole and seismic data, and structural analysis of the Himalaya as a fault-bend fold. When combined with seismic and geodetic data, this permitted the mapping of the megathrust ramp and flat, and an evaluation of the seismic hazard it poses, especially in those parts of India and Nepal that have not ruptured in the last century. Dr. Yeats was co-organizer of a workshop in Dehra Dun that had as its objective the establishment of a national earthquake hazards mitigation program for India. This workshop was followed by a paleoseismology short course, including the first paleoseismological trench investigations in the Himalaya; this course trained most of the young Indian scientists now working on earthquake geology, including studies of the 2001 Bhuj earthquake in Gujarat.

Principal Investigator, Active Faults of Pakistan. Dr. Yeats worked with the Geological Survey of Pakistan to develop an active fault database of northern Pakistan. As part of this project, he described in detail, with Pakistani colleagues, the Salt Range thrust and a set of active faults extending from south of Peshawar to Tarbela Dam. He also participated in a conference in Islamabad in January 2006 to advise the Pakistan government on response to the 8 October 2005 M7.6 earthquake that took the lives of more than 70,000 people, and in the mapping of the surface rupture by a Japanese-led team. Dr. Yeats was also a member of a field survey that discovered and mapped the surface rupture in and near the cities of Balakot and Muzaffarabad. With Chris Madden and Ahmad Hussain, also of ECI, Dr. Yeats is currently updating the fault database for northern Pakistan, including the source fault for the 2005 earthquake and a newly discovered blind thrust that will be evaluated for potential hazard to the Tarbela Dam across the Indus River and the Islamabad-Rawalpindi metropolitan area.

Co-Investigator, Surface Ruptures of the Gulang, Hongyaxi, Gaotai, and Shandan earthquakes in the Hexi Corridor, Western China. This project was organized and funded by the China Earthquake Administration. Mapping had as its objective the comparison of surface faulting and folding to magnitude for reverse faults (although the Shandan rupture turned out to be a spectacularly-exposed strike-slip fault). The results are

being added to a general worldwide comparison of the surface expression of reverse-fault earthquakes.

Principal Investigator, Analysis of the 1968 Inangahua Earthquake, Northwest South Island, New Zealand. The 1929 Murchison and 1968 Inangahua earthquakes in New Zealand, analogs to the 1971 and 1994 San Fernando Valley earthquakes, was analyzed for the New Zealand Institute of Geological and Nuclear Sciences.

SELECTED PUBLICATIONS

Yeats, R.S., 1973, Newport-Inglewood fault zone, Los Angeles basin, California: *American Association of Petroleum Geologists (AAPG) Bulletin*, Vol. 57, pp. 117-135.

Yeats, R.S., 1977, High rates of vertical crustal movement near Ventura, California: *Science*: Vol. 196, pp. 295-298.

Yeats, R.S., 1978, Neogene acceleration of subsidence rates in southern California: *Geology*, Vol. 6, pp. 456-460.

Yeats, R.S., Lawrence, R.D., Jamil-ud-din, S., and Khan, S.H., 1979, Surface effects of the 16 March 1978 earthquake, Pakistan-Afghanistan border; *in* Farah, A., and DeJong, K.A., (editors), *Geodynamics of Pakistan*: Geological Survey of Pakistan, pp. 159-361.

Yeats, R.S., Clark, M.N., Keller, E.A., and Rockwell, T.K., 1981, Active fault hazard in southern California: Ground rupture versus seismic shaking: *Geological Society of America (GSA) Bulletin*, Vol. 92, pp. 189-196.

Jackson, P.A., and **Yeats, R.S.**, 1982, Structural evolution of the Carpinteria basin, western Transverse Ranges, California: *American Association of Petroleum Geologists (AAPG) Bulletin*, Vol. 66, pp. 805-829.

Yeats, R.S., 1983, Large-scale Quaternary detachments in Ventura basin, southern California: *Journal of Geophysical Research*, Vol. 88, pp. 569-583.

Yeats, R.S., and Olson, D.J., 1984, Alternate fault model for the Santa Barbara, California earthquake of 13 August 1978: *Seismological Society of America (SSA) Bulletin*, Vol. 74, pp. 1545-1553.

Yeats, R.S., Khan, S.H., and Akhtar, M., 1984, Late Quaternary deformation of the Salt Range of Pakistan: Geological *Society of America (GSA) Bulletin*, Vol. 95, pp. 858-966.

Yeats, R.S., McDougall, J.W., and Stitt, L.T., 1985, Cenozoic geology of the Val Verde 7 1/2-minute quadrangle and south half of the Whitaker Peak 7 1/2 minute quadrangle, California: *U.S. Geological Survey Open-File Report 85-587*, 23p., maps scale 1:24,000.

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Yeats, R.S., and Berryman, K.R., 1987, South Island, New Zealand, and Transverse Ranges, California: A seismotectonic comparison: *Tectonics*, Vol. 6, pp. 363-376.

Yeats, R.S., Lee, W.H.K., and Yerkes, R.F., 1987, Geology and seismicity of the eastern Red Mountain fault, Ventura County, California: *U.S. Geological Survey Professional Paper 1339*, pp. 161-167.

Yeats, R.S., 1987, Late Cenozoic structure of the Santa Susana fault zone, California: *U.S. Geological Survey Professional Paper 1339*, pp. 137-160.

Yeats, R.S., 1988, Late Quaternary slip rates on the Oak Ridge fault, Transverse Ranges, California: Implications for seismic risk: *Journal of Geophysical Research,* Vol. 93, pp. 12,137-12,149.

Yeats, R.S., Huftile, G.J., and Grigsby, F.B., 1988, Oak Ridge fault, Ventura fold belt, and the Sisar decollement, Ventura basin, California: *Geology*, Vol. 16, pp. 1112-1116.

Stein, R.S., and **Yeats, R.S.**, 1989, Hidden earthquakes: *Scientific American*, Vol. 260, No. 6, pp. 48-57.

Yeats, R.S., and Hussain, A., 1989, Zone of late Quaternary deformation in the southern Peshawar basin, Pakistan: *Geological Society of America Special Paper 232*, pp. 265-274.

Yeats, R.S., Calhoun, J.A., Nevins, B.B., Schwing, H.F., and Spitz, H.M., 1989, The Russell fault: An early strike-slip fault of the California Coast Ranges: *American Association of Petroleum Geologists (AAPG) Bulletin*, Vol. 73, pp. 1089-1102.

Yeats, R.S., and Schwartz, D.P., 1990, Paleoseismology: Extending the record of earthquakes into prehistoric time: *Episodes*, Vol. 13, pp. 9-12.

Yeats, R.S., and Taylor, J.C., 1990, Saticoy oil field – U.S.A., Ventura basin, California; *in* Beaumont, E.A., and Foster, N.H., (compilers), *Atlas of Oil and Gas Fields*: Structural Traps III, Tectonic Fold and Fault Traps: American Association of Petroleum Geologists Treatise of Petroleum Geology, pp. 199-219.

Hussain, A., **Yeats, R.S.**, and Pogue, K., 1990, Geologic map of Attock-Cherat Range and adjoining areas, N.W.F.P. and Punjab, Pakistan, 1:100,000: Geological Survey of Pakistan.

Yeats, R.S., and Beall, J.M., 1991, Stratigraphic controls of oil fields in the Los Angeles basin: A guide to migration history; *in* Biddle, K.T., and Phelps, D., (editors), Los Angeles basin volume: *American Association of Petroleum Geologists (AAPG) Memoir 52*, pp. 221-237

Yeats, R.S., and Lillie, R.J., 1991, Contemporary tectonics of the Himalayan frontal fault system: Folds, blind thrusts and the 1905 Kangra earthquake: *Journal of Structural Geology*, Vol. 13, pp. 215-225.

Yeats, R.S., and Rockwell, T.K., 1991, Quaternary geology of the Ventura and Los Angeles basins, California; *in* Morrison, R.B., (editor), Quaternary non-glacial geology: Conterminous United States: *Geological Society of America Decade of North American Geology*, Vol. K-2, pp. 185-189.

Van Dissen, R., and **Yeats, R.S.**, 1991, Hope fault, Jordan thrust, and uplift of the Seaward Kaikoura Range, New Zealand*: Geology*, Vol. 19, pp. 393-396.

Yeats, R.S., 1991, Oak Ridge fault, Ventura basin, California: Slip rates and late Quaternary history: *U.S. Geological Survey Open-File Report 89-343*, 30 p., 6 pl. including maps at 1:48,000 scale.

Yeats, R.S., Nakata, T., Farah, A., Fort, M., Mirza, M.A., Pandey, M.R., and Stein, R.S., 1992, The Himalayan frontal fault system: *Annales Tectonicae,* Supplement to Vol. 6, pp. 85-98.

Christiansen, R.L., and **Yeats, R.S.**, 1992, Post-Laramide geology of the U.S. Cordilleran region; *in* Burchfiel, B.C., Lipman, P.W., and Zoback, M.L., (editors), The Cordilleran Orogen: Conterminous U.S.: *Geological Society of America Decade of North American Geology*, Vol. G-3, pp. 261-406.

Werner, K.S., Nabelek, J.L., **Yeats, R.S.**, and Malone, S.D., 1992, The Mount Angel fault – Implications of seismic-reflection data and the Woodburn, Oregon, earthquake sequence of August 1990: *Oregon Geology*, Vol. 54, No. 5, pp. 112-117.

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Levi, S., and **Yeats, R.S.**, 1993, Paleomagnetic constraints on the initiation of uplift on the Santa Susana fault, western Transverse Ranges, California: *Tectonics*, Vol. 12, pp. 688-702.

Pantosti, D., and **Yeats, R.S.**, 1993, Paleoseismology of great earthquakes of the late Holocene: *Annali di Geofisica,* Vol. 36, pp. 237-257.

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