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The 1993 M4.7 Kuwait earthquake: Induced by the burning of the oil fields

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ABSTRACT

A M4.7 earthquake in otherwise seismically inactive Kuwait occurred under the cluster of the country's most productive oil field on June 2, 1993 - only 25 months after 539 out of the region's 770 producing oil wells were set on fire or left gushing by the invaliding Iraqi armed forces. It is probable that this solitary earthquake was caused not by tectonic forces but by rapid and regional depletion of pore pressure, which can induce shear stress sufficient to cause massive subsurface rock failure.

Keywords: Earthquake, Induced Earthquake, Kuwait, oil Gushing

INTRODUCTION

On June 2, 1993, a M4.7 earthquake, followed by a M3.2 aftershock on June 4, 1993, occurred in southern Kuwait (Table 1). Despite its modest magnitude, the earthquake was widely felt. It caused measurable damage and some panic in Kuwait city approximately 150 km away. One reason for this disruption is that earthquakes had rarely been felt in Kuwait, an area that was generally assumed to be almost earthquake-free. This assumption is supported by the very low known historical seismicity of Kuwait, as shown in Figure 1. Furthermore, to date no active faults have been recognized or delineated by seismicity in Kuwait.

Table 1. Epicenteral locations and times of the two 1993 earthquakes in kuwait.

1. June 2, 1993; Time 22:01:55; Location Lat. 28.88; Long. 47.64; Depth 20km
2. June 4, 1994; Time 12:23:18; Location Lat. 28.98; Long. 47.44; Depth 20km

Because the epicenter of this earthquake is far from the active Zagros tectonic belt, and researchers have located very few events in kuwait over the past 40 years or so, a purely tectonic cause is unlikely.

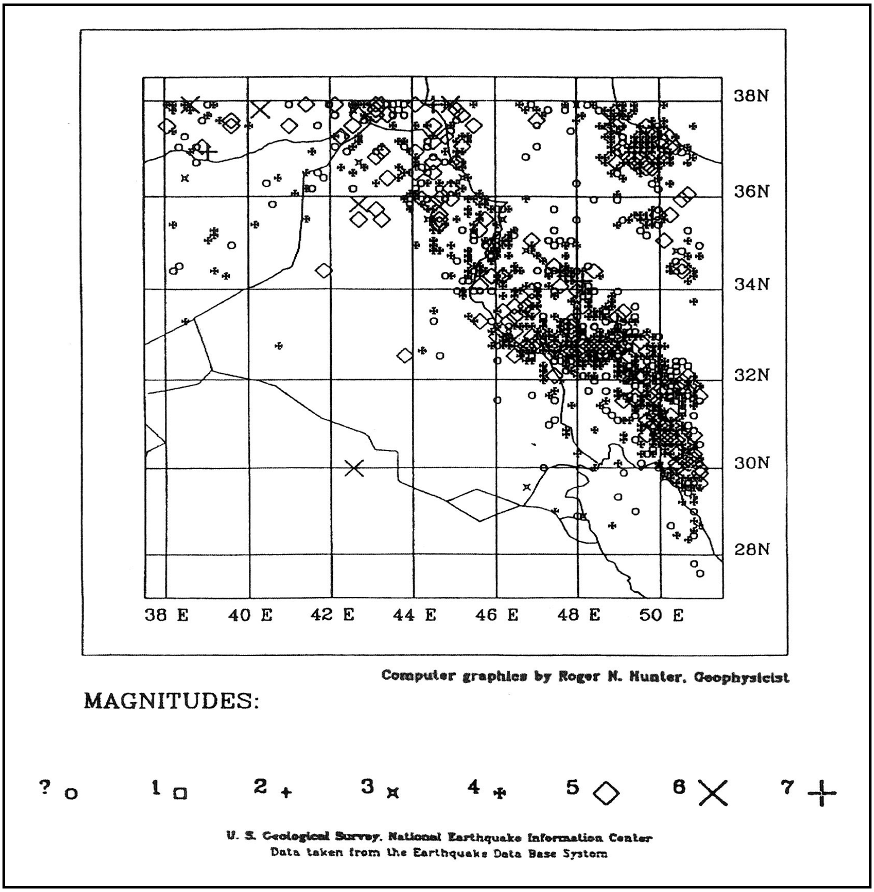

Figure 1. Earthquake epicenters in Iran, Iraq and Kuwait, 1950 to 1980 (data from USGS, National Earthquake Information Center). Kuwait is seismically very quiet.

WAS IT AN INDUCED EARTHQUAKE?

Could the earthquake be related to the oil field activity instead of pore tectonics? Although its depth is not well determined, apparently the epicenter fell within the area of the large, productive cluster of oil fields in Southern Kuwait (Table 2, and Figures 2 and 3). The fields of this cluster, with 770 wells, produce 80% of Kuwait's oil. They have been in production for over 54 years, and subject to injection of water and gas to improve recovery during the past 20 years. The June 1993 earthquake occurred only 25 months after two thirds of the wells were set on fire by the Iraqi armed forces. These fires and gushing caused on enormous and uncontrolled outflow of oil over a period of eight months.

Table 2. Southern Kuwait oil fields: Number of drilled, ignited, gashed, damaged, and unharmed fields during the Gulf war.

Fields	Drilled	On Fire	Gushing	Damaged	Intact
Magwa	147	98	6	21	15
Ahmadi	89	60	2	18	6
Burgan	423	292	24	28	67
Minagish	40	2	?	7	1
Umm Gudair	44	27	3	11	2
Dharif	4	0	0	0	3
Abduliyah	5	0	0	0	4
South Umm Gudair*	18	0	0	0	16
Total	770	504	35	85	114

Past experience in other oil fields (e.g., Segall 1989, Grasso 1993) suggests at least three ways that the Souther Kuwaiti oil field operation might have precipitated this earthquake:

- Oil extraction since 1940.
- Fluid injection since 1975, including massive gas injection since late 1991.
- Super rapid depletion associated with burning wells.

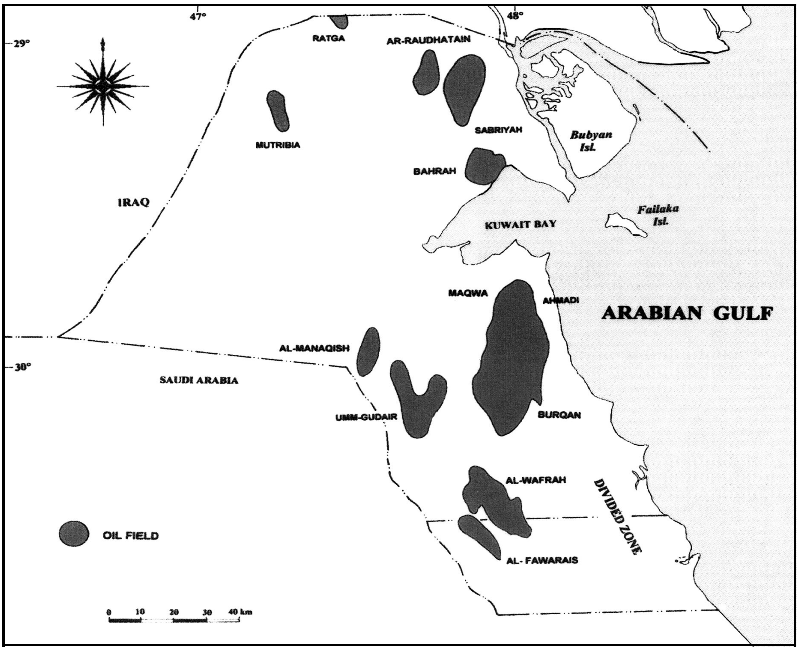

Figure 2. Distribution of oil fields in the Southern Kuwait oil field cluster.

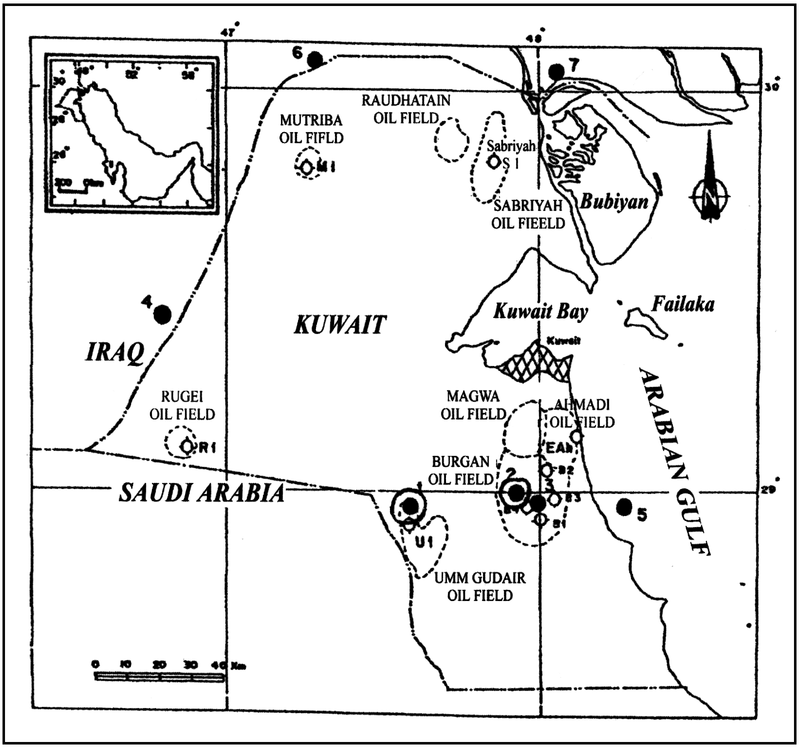

Figure 3. The estimated epicentral location of the unusual June 2, 1993 M4.7 earthquake (#1 circled black circle) & aftershocks (block circles).

Existing data together with numerical and theoretical models suggest that prolonged production can cause shear stresses that induce seismic activity in oil and gas fields. Empirical evidence includes data from such diverse geological settings as Canada (Wetmiller 1986), the USA (Kovach 1974, Pennington *et al* 1986, Doser *et al.* 1993, Segall 1992, France (Grasso & Wittlinger 1989), and Russia (Riznichenko 1960).

Segall (1989, 1992) and McGarr (1991) have modeled how stresses change, and subsurface rocks fail because of recovery-related changes in pore pressure. According to Segall (1989, 1992) fluid recovery can cause earthquakes because the reduction in fluid mass and pressure causes rock volume to shrink, which results in shear stresses. The magnitude of the shear stress induced by recovery is to a first order proportional to the cumulative production of a given field, and hence to the lateral extent of the producing region. As illustrated in Figure 4, the latest increases in shear stresses tend to occur above and beneath the production zones. These stresses are superimposed on the pre-existing tectonic stress field. Together, they can cause faults to undergo sudden earthquake slip in regions surrounding the recovery area, especially above and below it. The maximum magnitude and number of earthquakes induced by fluid withdrawal are expected to be proportional to the amount of withdrawn fluid and the reduction of pore pressure in the reservoir region. Due also to the geometry of the situation, the movements induced by this process tend to be of the thrust type.

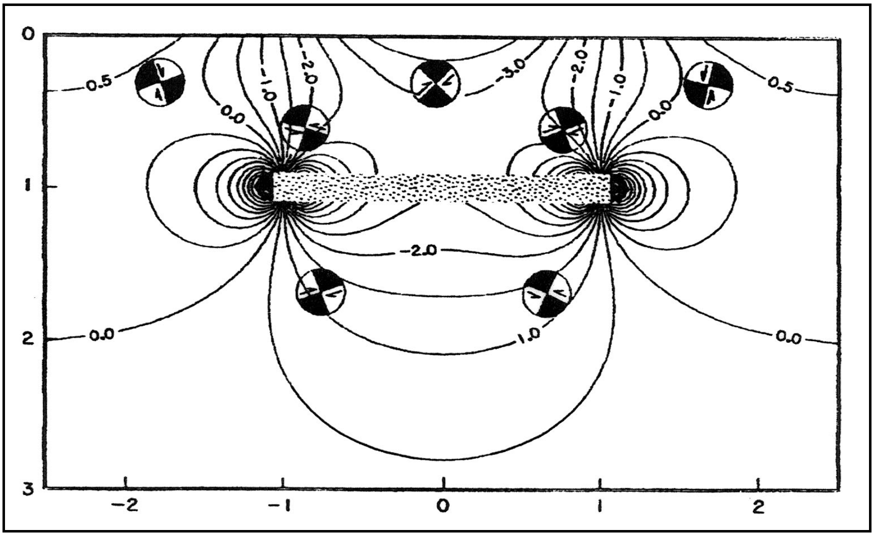

Figure 4. Relative changes in horizontal stress (tension is positive) within a homogeneous Elastic half space where a poroelastic disk shaped reservoir is embedded. Simulated focal mechanisms indicates planes of maximum shear stress when Reservoir is depleted (from Segall, 1989).

McGarr (1991) proposed that deeper crustal earthquakes can be caused by fluid withdrawal resulting from isostatic stresses. This mechanism may operate under very large fields with lateral dimensions on the order of the thickness of the brittle crust. The removal of a large mass (the recovered fluid) causes deficiency in the region, so that isostatic uplift may be induced, and crustal stresses may evolve when the uplift is prevented by the stiffness of the crust. These stresses can also engender earthquakes. It is therefore possible that the main 1993 Kuwait earthquake was the result of the cumulative 54 years production from the Southern Kuwait oil field. It is not clear, however, why the earthquake occurred in 1993.

Fluid injection into reservoirs can also induce earthquakes, as exemplified by the Rangely, Colorado experiment (Healy et al. 1968, Raleigh et al. 1972). During injection, subsurface fluid pressures increase in the injection region. This reduces the normal effective stress on existing faults, allowing any preexisting shear stress to overcome the fault's frictional resistance, thus leading to earthquake rupture. Seismicity caused by pressurized injected fluids is expected in normal and strike-slip tectonic environments, but not in a thrust setting. The location of injection-induced earthquakes is typically restricted to the region of injection, and their magnitude is related to the volume of the injected fluid. In

Southern Kuwait, injection of water and gas to improve recovery began in 1975 and has continued.

The fields have also been subjected to massive gas injection since November 1991 is an attempt to rehabilitate them following the Iraqi war fires. But injection operations involve closely spaced injectors and producer wells, so the lateral extent of pore pressure change is localized, and the net change in fluid volume is small or moderate. It is not very likely therefore that the gradual injection to enhance recovery in Southern Kuwait before the Gulf war or the rapid injection since, could have caused a M4.7 earthquake.

DISCUSSION

The oil fields of southern Kuwait experienced what must be a historically unique episode of field-wide, super fast outflow. This uncontrolled depletion was caused by the fires that engulfed 504 of the 770 wells (Fig 5) and the gushing of 35 additional wells. The fires lasted from February 22, 1991 until November 6, 1991, when the last wells were extinguished and capped (Table 2). The volume of oil loss through this unchecked flow is estimated at two million barrels, which corresponds to approximately a quadrupling of the historical recovery rate, and amounts to a loss of two percent of Kuwait's recoverable reserves.

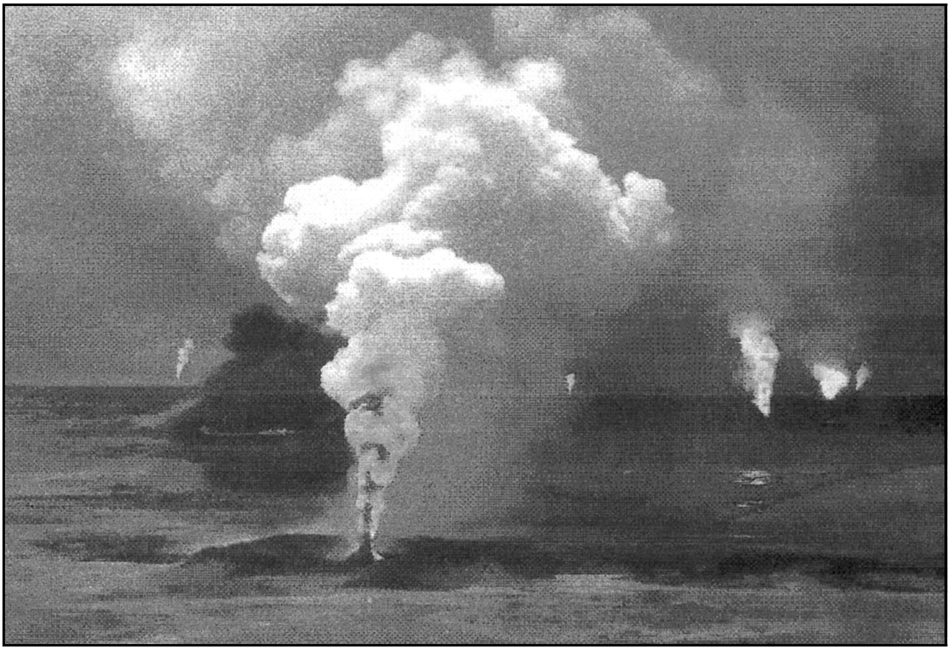

Figure 5. Burning oil wells in Kuwait, before they were extinguished in late 1991.

The large and widespread decline in pore pressure that this outflow caused throughout the entire field must have generated large shear stresses, firstly because of the overall shrinking of the reservoir volume. Secondly, because of the rapidity of the pressure decline, it created large transient pore pressure gradients, which could further enhance the buildup of shear stress, especially around the reservoir where such gradients may induce seismicity as well (Doser *et al.* 1993).

The limited data available, and the uniqueness of the recent history of the Southern Kuwait fields preclude a definite conclusion regarding the cause of the 1993 earthquake. However, of the three production-related possibilities, the wide field rapid outflow and pressure decline associated with the well fires is the most likely cause of the M4.7 July 1993 earthquake.

This theory implies that the area's risk of further earthquakes in the near future is gradually decreasing, because the runaway outflow has ceased. Thus, the local high pore-pressure gradients that can induce large shear stresses are gradually dissipating by pore fluid diffusion. However, the 1993 earthquake indicates a lingering potential for production-induced earthquakes in Southern Kuwait and Kuwait in general.

Especially because of the lack of earthquake awareness and preparedness in Kuwait, detailed studies are needed to understand more quantitatively the factors affecting the seismic potential of Kuwait, including the prevailing tectonic stresses and the production history of the main oil fields. These studies might include the recording of low-magnitude earthquakes, from which seismogenic faults can be mapped and the determination of the frequency-magnitude relation for Kuwait from which the probability of larger future events can be estimated. Because, as discussed above, the earthquake mechanism (normal, thrust or strike slip) is indictive of the responsible fluid process, it would be especially useful to establish, in the future, the mechanism of the 1993 event, or subsequent and future events in Kuwait. This could in turn begin to clarify the nature of the seismicity of Kuwait, and the roles of oil recovery.

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زلزال الكويت عام 1993 بقوة 4,7 درجة
هل تولد نتيجة إشعال آبار النفط؟

فريال بوربيع* و إيموس نور**

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خلاصة

وقع زلزال بقوة 4,7 درجة في الكويت التي تعتبر من المناطق غير النشطه زلزاليا في الثاني من يونيو 1993 في منطقة بها أكبر تجمع للآبار المنتجه للنفط وذلك بعد 25 شهرا من تدفق النفط وإشعال 539 بئرا من 770 من الآبار المنتجه بفعل قوات الغزو العراقي المسلحه. وقد يرجع السبب في حدوث هذا الزلزال إلى الإستنزاف الإقليمي والنقص السريع في الضغط المسامي الذي يمكن أن يولد من إجهادات القص ما يكفي لتصدع كبير في الصخور تحت السطحية للمنطقه.