Geophysics and weapons inspection

To dig or not to dig? That is (at least) one question

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Figure 1. The only means of travel in and out of Iraq during the UNSCOM period was taking the UN cargo flights between Bahrain and Baghdad.

Figure 2. The geophysical team and equipment must be easily transportable in a jeep or two or onboard a helicopter.

Figure 3. A handheld electromagnetic sensor was one of the workhorse geophysical instruments to cover large areas very quickly.

Figure 4. A large copper tube assembly made for isotope separation for the Iraqi nuclear program. A magnetometer once missed it because of its nonferrousness. The electromagnetic data led to its excavation.

Figure 5. Surveying over a warhead disposal area that included shallow lakes.

Figure 6. Looking for suspect ordnance items in a chicken feed farm.

Until 1996, international weapons inspection and arms control missions did not include sophisticated geophysical investigation. On-site inspections depended largely on visual observation, personal communication, and physical searches. As part of the first geophysical survey team to operate under international auspices, we were party to both the technical and the human challenges of using geophysical instruments in less-than-ideal circumstances. This article introduces our experience as "geophysical weapons inspectors." Initially, the paper provides background to this unprecedented application of geophysics to an international monitoring regime. It then describes typical procedures and specific tasks and concludes with more personal reflections about our participation in this (to us) novel undertaking—one in which some of our geophysical colleagues are likely to be active in the future.

The authors are, of course, aware that this is a topic of intense controversy around the world. Therefore, at the suggestion of the *TLE* Editorial Board, we offer these additional introductory comments in an attempt to answer any questions in the reader's mind regarding our motivation or the facts presented in the following section.

The "hard" information in the background section is, we believe, essential to provide a factual nonbiased overview of what the weapons inspection regime was and what it accomplished. The numbers and the resulting assessments are in the public domain as part of the official reports from the UN Special Commission (UNSCOM), United Nations Monitoring, Verification and Inspection Commission (UNMOVIC), and the International Atomic Energy Agency (IAEA) to the United Nations. The "suggested reading" section at the end of this article lists the addresses of Web sites where the full reports can be accessed.

The "reflections" at the end of the article are clearly demarcated as the personal opinions of the authors. We did not intend to promote any political agenda in this article, particularly in this section, and none should be inferred.

Background. In April 1991, soon after the first Gulf War, the United Nations Security Council established UNSCOM. It had two basic functions: to inspect Iraq's chemical, biological, and certain ballistic missile weapons capabilities—including production and storage facilities—in order to oversee their elimination or destruction and to monitor and ensure long-term compliance. The commission was also to assist IAEA with similar tasks in the nuclear field. According to UN reports, by 1998 UNSCOM had destroyed over 40 000 chemical weapons and nearly 500 tons of chemical warfare agents. It was effective in the biological weapons front as well: Iraq was known to have imported 38 tons of growth media for agents such as anthrax and botulinum in 1988, of which UNSCOM had destroyed 11 tons by 1996. Concurrently, IAEA, with UNSCOM cooperation, uncovered and dismantled Iraq's clandestine nuclear program. Under the economic sanctions imposed after the first Gulf War, there was no commercial air traffic in Iraq. The only means of travel was using regular UN cargo flights between Bahrain and Baghdad to transport inspectors and equipment (Figure 1).

The foundational premise of weapons inspection is a form of accounting. A stockpile of particular weaponry is

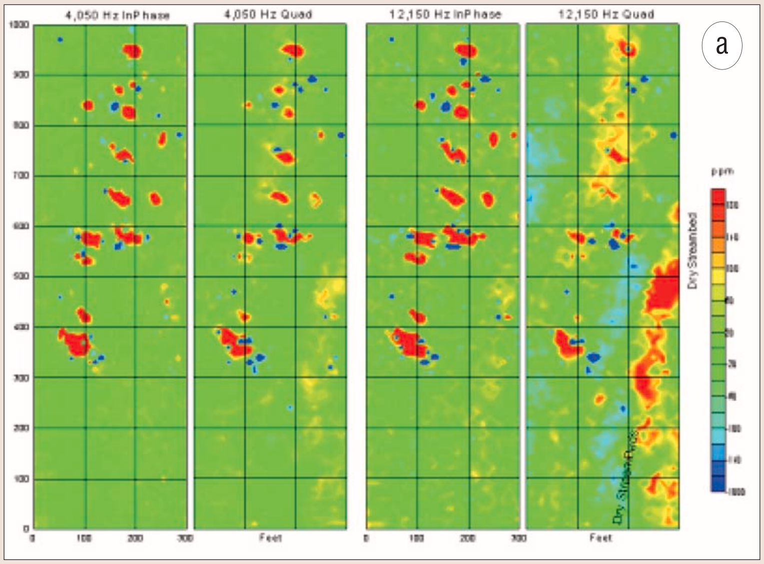


Figure 7. *(a) Two-frequency electromagnetic data over a 7-acre nuclear burial site. The grid size is 100 ft by 100 ft. The burial pits are indicated by red anomalies. Red-yellow bands in the high-frequency quadrature data were identified as dry streambeds. (b) Excavation based on data shown in Figure 7a. Most items excavated at this site, carefully packaged on wooden pallets, contained various nuclear-related parts and instruments.*

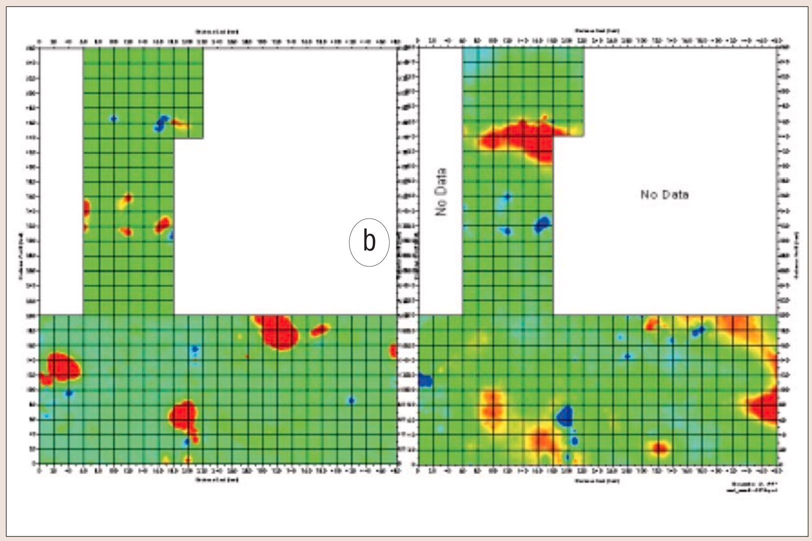


Figure 8. *(a) A chemical weapons site where chemical agents were disposed in the ground. (b) Electromagnetic data at the site of Figure 8a: in-phase (left) and quadrature (right) data at 12 270 Hz. The grid size is 20 × 20 ft. The in-phase map shows buried metallic debris and the chemical plume is indicated in quadrature. We were instructed not to enter the areas labeled "No Data" because of reportedly high toxicity.*

compared to a document that describes its type and quantity; the document might have come voluntarily from the state subject to inspection (this is called a "declaration") or through intelligence sources. Problems arise when the two quantities do not agree, leading to disputes about the reasons for and the whereabouts of missing material. In the case of documents that do not adequately account for uncovered weapons, it is logical to conclude that the declaration is deliberately or unintentionally incomplete, or that the intelligence is faulty. In the case of missing weapons, plausible scenarios include that the missing items have been (1) voluntarily destroyed and discarded to avoid inspection, (2) intentionally hidden, or (3) truly misplaced and forgotten by anyone now living. An inspection is finished only if and when all quantities of weaponry, intact or in pieces, have been found and accounted for according to documented quantities. Even those that have been destroyed and buried voluntarily must be exhumed and inventoried until the two quantities eventually agree.

Most arms control verification regimes begin with a basic assumption of compliance, but this has not been the case in Iraq. Partly because of the intrusive nature of the inspection tasks, Iraq became progressively confrontational with UNSCOM. Then, in 1995, a prominent member of the government of Iraq defected to Jordan, and his statements led to the discovery of trailer-loads of hidden documents related to Iraqi weapons programs. These documents revealed that the Iraqi government had organized systematic concealment efforts against UNSCOM inspectors. The concealment included burials of weapons caches both within buildings and outdoors. This development helped explain why UNSCOM had not been able to "balance the accounts" between actual weapons and the documents that ostensibly described them.

As a result, UNSCOM decided in 1996 to employ geophysical technology to inspect suspected burial or concealment sites. This decision resulted in the birth of "geo-sensing teams" to carry out geophysical data acquisition and interpretation and, if necessary, to assist excavation activities. As part of a UN operation, a geo-sensing team needed to consist of geophysicists, field technicians, interpreters, and paramedics from many member countries; we at U.S.-based Weston Geophysical and Geophex joined colleagues from nations such as France, Germany, Australia, and Canada.

UNSCOM continued its operations until Iraqi cooperation virtually ceased in 1997; weapons inspectors were expelled—then readmitted—until about a year later, when Iraq ended its official ties with UNSCOM. As a consequence, and after official UN condemnation of Iraq's noncompliance, U.S. President Clinton ordered a three-day bombing in late 1998 (Operation Desert Fox).

Inspections resumed briefly for a few months in late

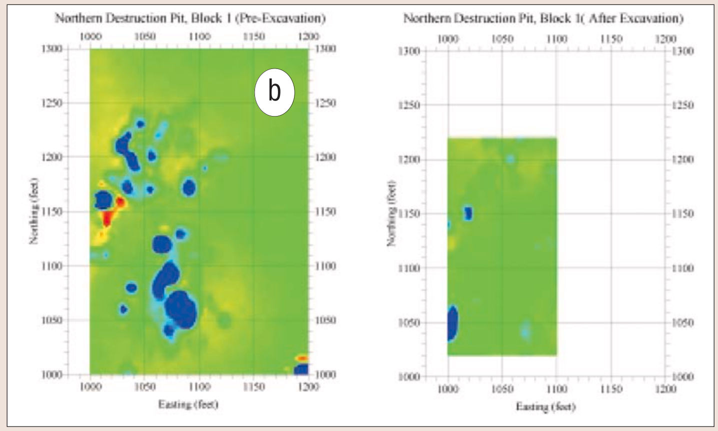


Figure 9. *(a) A disposal site near Tikrit containing missile components. (b) Electromagnetic data over the disposal site in Figure 9a before (left) and after (right) the excavation. The grid size is 50 × 50 ft.*

Figure 10. *(a) The Navy's* Zodiac *inflatable boat was frequently used for conducting geophysical surveys over water. Typical sensors included a side-scan sonar, magnetometers, and, at times, electromagnetic sensors. (b) Anchored buoys were used to mark anomalies over water in real time. A recovery team dove into the murky river to inspect each anomaly and retrieve the finds.*

2002 and early 2003 under the newly organized UNMOVIC that had been created in December 1999 to replace UNSCOM. UNMOVIC ceased its Iraq operations in March 2003, when the second Gulf War began.

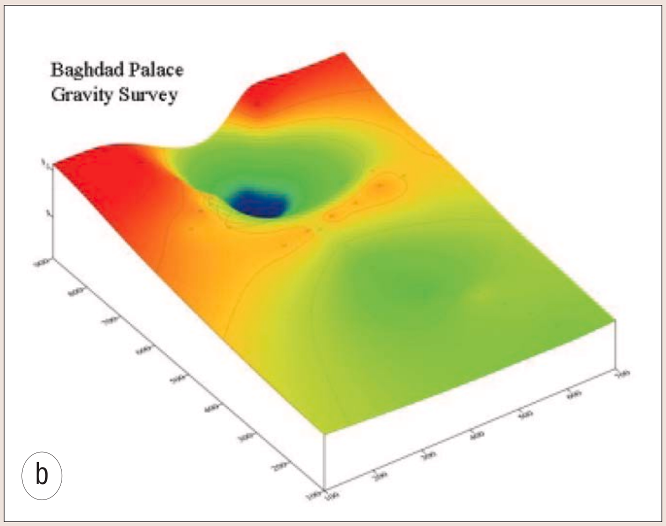
The team. Vincent Murphy of Weston Geophysical Engineers in Northborough, Massachusetts (a wholly-owned subsidiary of Geophex in Raleigh, North Carolina), headed the U.S. team for the geo-sensing missions. The team, 3-8 people depending on the scale of the particular mission, made 12 trips under UNSCOM, each lasting 2-6 weeks. The team visited nearly 100 individual sites in Iraq from late 1996 through 1998 under UNSCOM and for a brief period in early 2003 under UNMOVIC. The sites covered more or less the entire country, spanning from the southern port city of Basra near the Persian Gulf to historic Mosul, the biblical city of Jonah, toward Turkey where the mighty Tigris River originates.

An UNSCOM group led by a chief inspector often would be assembled before arriving in Iraq to plan the best deployment of the geo-sensing team or teams. Discussions between UN personnel and weapons, science, and intelligence specialists characterized the nature of the targets and determined the level of effort necessary to hunt for the banned weapons once the team arrived in Iraq. Sometimes the target could not be revealed until the team actually visited the site; this happened typically when the inspection target was high profile or the intelligence source was especially sensitive. The team used two modes of operation: when the target items were thought to be buried, we immediately went into action with all the geophysical tools at our disposal; when many possible concealment scenarios existed, we were "on standby" while a multifaceted professional group investigated a facility.

The instruments. For the first few missions, we brought every conceivable geophysical sensor in the toolbox—two sets each, for contingencies. We took instruments for magnetic, gravity, electrical, electromagnetic, ground-penetrating radar, radiometric, seismic refraction, and reflection surveys; in addition, we often carried underwater sensors such as side-scan sonar and other towed sensors. It soon became apparent, however, that the majority of these instruments could not meet situational requirements because most surveys must be completed on the spot, preferably in a single day, as speedily as possible. Within these parameters, data must be interpreted, anomalies identified, and, if necessary, target areas must be painted on the ground to direct the excavation crew. Further, geophysical instruments, auxiliary equipment, and the team members themselves must be easily transportable via a jeep or two or onboard a helicopter (Figure 2).

These requirements left only a few sensor types appropriate for daily use; most practical were handheld magne-

Figure 11. (a) Gravity survey in a palace compound. (b) A gravity anomaly under flooring led us to a palace wine cellar.



tometers and electromagnetic sensors because they provide a rapid, unambiguous first look at a site. We avoided instruments that require ground contact (e.g., geophones, electrodes) because of potential soil contamination at many weapons sites we visited. On several occasions, we had to conduct geophysical surveys in protective garments — disposable coveralls, booties, gloves, head covers, and at times, respirators — in the summer desert. Lugging cumbersome equipment rather than relatively lightweight portable sensors would have made working in these difficult and dangerous conditions virtually impossible.

As our activities progressed, we eventually winnowed down our workhorse sensors to a few magnetometers and electromagnetic sensors that allowed individual surveyors to cover large areas quickly (Figure 3). Indeed, fast deployment, surveying, and assessment made possible by these instruments frequently let the inspection groups cover more ground, literally and figuratively. Often there was time to investigate secondary targets, either ones already classified as lower priority or ones identified on-site when team specialists found irregularities or discrepancies.

The inspections. More often than not, our team conducted "surprise" site inspections that would allow only a few hours for data acquisition and processing followed by excavations as warranted. Some sites disclosed only "junk" materials, while others contained missile nose cones, engine parts, and even traces of biological and chemical agents on buried munitions. A few of the disclosed destruction sites extended over tens of acres, requiring multiple-crew operations and several backhoes for the follow-up digging.

All excavations that ensued from geophysical investigations were based on electromagnetic and occasionally on magnetic data. Items uncovered included missile parts (turbine blades, igniters), numerous ordnance items, and many parts related to various weapons projects, including the nuclear program. These items were either secreted in pristine condition, obviously concealed, or voluntarily destroyed and haphazardly buried. The Iraqi "minders" who accompanied each team disclosed many of the latter type of items to us, but there were some surprises regarding deliberately concealed items. Figure 4, for instance, shows a large circular copper tube assembly used for electromagnetic isotope separation in the Iraqi nuclear weapons program. The site was once declared "clean" by a magnetic survey that missed this gigantic nonferrous object, but the electromagnetic sensor readily detected it.

The ability to utilize geophysical instruments inventively at many locations that had been thought impossible to inspect kept both the Iraqis and even some chief inspectors off guard. Our handheld sensors let us "see" beneath muddy shallow-water lake beds (Figure 5) and through piles of organic material (Figure 6) as well as beneath soil and concrete as we looked for buried unexploded ordnance, and we could survey relatively large areas in a fairly short time period. This thorough coverage provided the weapons inspectors with the confidence to state that targeted sites had been investigated to their satisfaction. Virtually every visited site contained detectable materials. Although most items were deliberate discards or junk (and much of these needed to be detected so they could be inventoried accurately), there were also significant finds, such as components used in nuclear weapons production and in prohibited missile programs.

One geophysical success story came from a desert site about 60 km northwest of Baghdad, where Iraq was believed to have conducted nuclear-related activities. An initial excavation produced a cache of telltale precision-machined aluminum pipes that were part of a nuclear program. Subsequently, we conducted an electromagnetic survey over a seven-acre desert area near the first excavation. Figure 7a shows the electromagnetic data at two different frequencies, each with in-phase and quadrature, over the area. Buried metallic caches are indicated by red anomalies visible in all the data, and most clearly on the in-phase maps; the red-yellow bands most notable on the high-frequency quadrature map were identified as dry streambeds. These data were acquired and processed on site during a single field day and used to direct the excavation operation shown in Figure 7b. Most items recovered from this site were packaged carefully on wooden pallets wrapped in plastic sheets, indicating deliberate concealment. This treasure trove consisted largely of pristine nuclear-related parts and instruments, including gold-plated valves for reactors and other high-value items.

A different sort of task involved a chemical weapons site, which had been used to bury warheads and reportedly to dump chemical munitions agents. The Iraqis insisted that, in fact, several tons of missing chemical agent had been poured into the ground in this area, and we needed to verify this claim (Figure 8a). Our electromagnetic survey yielded interesting results: the in-phase map (Figure 8b) shows buried warheads and debris (the red anomalies), yet a chemical plume, much subtler in conductivity contrast, is visible only in the quadrature map. This large anomaly, also in red, starts from the upper left (the reported dumping location) and moves to the lower right of the map, a migration direction coincident with the groundwater down-gradient of the site. Based on these data, several holes were augured to obtain soil samples for chemical analyses and the Iraqi claim about the missing chemical agents was proven correct.

Throughout Iraq, geophysical data and subsequent soil sampling or full-scale excavations helped inspectors to inventory missing quantities of particular weapons and weapons components. Sometimes these items were completely unknown to Iraqis, sometimes they confirmed Iraqi claims, and sometimes they provided a basis for challenging Iraqi declarations. For instance, the findings at a site near Tikrit (Figure 9a) did not tally with the documents describing it. Our data showed small anomalies (Figure 9b), and the single truck load of recovered missile parts excavated pursuant to the electromagnetic data was much less than the original volume once stored at the site.

Geophysical surveys at water-covered sites required the same element of surprise as the land-based inspection. To accomplish this, portable rubber rafts and powered inflatable boats, the Navy's Zodiac (Figure 10a), were used to investigate water sites. A dive team accompanied us to assist in the recovery of detected objects (Figure 10b).

On occasion, our surveys yielded results that turned out to be red herrings. At a site along part of the Samarra Canal we searched with side-scan sonar, magnetics, and electromagnetics; we detected missile-sized objects placed nearly parallel on the canal floor. When the dive team investigated them in muddy water with less than a foot visibility, they turned out to be only cast-iron irrigation pipes. In palace compounds (Figure 11a), networks of tunnels were confirmed, and gravity surveys showed negative anomalies (Figure 11b); when one promising anomaly was accessed, however, we found an empty underground storage area paneled in fine woods that appeared to be an unused palace wine cellar.

Reflections. Conducting geophysical surveys in Iraq was always challenging and often professionally rewarding. We were able to apply our science and technology to new problems in unfamiliar environments, be they hastily organized underwater geophysical surveys along the Euphrates river or figuring out how to conduct a survey safely in a 140°F desert filled with known chemical and biological warheads. Perhaps the biggest challenge, however, was the waiting game.

We waited a lot in Iraq. We waited in bifurcated convoys, one column of UN jeeps followed by another column of Iraqi minders. We waited in featureless desert terrain because faulty intelligence, directions, and air photos made it easy to get lost. We waited outside facilities while both sides performed the apparently obligatory slow-motion protocol dances.

This particular form of waiting increased in early 1998 when the UN insisted on unfettered access everywhere, while Iraq put the presidential palaces off-limits under a claim of sovereignty. Many tedious confrontations ensued at palace facility entrances. While both sides argued at the main gate (a process further retarded by translation necessities), a UN helicopter would hover over the compound to observe boxes being moved from one building to another, and newly loaded vehicles driving out through the back gate. The chief inspector would drag out his satellite phone to call UN headquarters in New York for further instructions while anti-aircraft guns mounted on sentry roofs kept pointing at the convoy where we waited in the gathering heat. As Claudius said to Laertes in act four of *Hamlet*,

> . . . that we would do
> We should do when we would; for this 'would' changes
> And hath abatements and delays as many
> As there are tongues, are hands, are accidents.

We started realizing that we, the geophysical team, were pawns in this geopolitical game. Although we had made what we considered significant contributions to the search for truth about Iraq's weapons, the time was becoming more and more out of joint. Indeed, it was running out . . . and it was time for us to leave. TLE

Suggested reading. The reports to the United Nations cited in this article are available at these Web sites:

http://www.un.org/Depts/unscom/
http://www.unmovic.org/
http://www.iaea.org/worldatom/Programmes/ActionTeam/
http://www.defenselink.mil/specials/desert_fox/

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