Detecting Massed Troops with the French SPOT Satellites
A Feasibility Study for Cooperative Monitoring

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Introduction

Originally designed as an imaging system for cartographers and resource managers, the French SPOT satellites have attracted a far more diverse group of end users — including arms control analysts. However, since the SPOT satellite was not designed exclusively for arms control and confidence building applications, its utility must be tested empirically.

One application that merits closer examination is the use of SPOT panchromatic imagery (10 meter resolution) to detect and monitor troops massing along an international border, near a demarcation line, or at key transportation nodes deep within a country. If commercial imagery acquired by the SPOT satellites or by comparable remote sensing systems could be used for such a purpose, the analysis of this openly available imagery could provide states with a rudimentary early warning capability against offensive attack preparations. Such a capability could be used by states individually or collectively to monitor troop movements within the region and verify the absence of troops in agreed demilitarized zones.

This paper details the results from an empirical study that tested the utility of SPOT imagery for detecting troop concentrations in a desert environment. Two archived SPOT panchromatic images of a Saudi-Iraqi border region were obtained. One image was acquired approximately five months before the start of Operation Desert Storm; the other was acquired almost two weeks after the air war began and four weeks before the start of the ground war. The "before" and "after" images were analyzed to determine whether allied ground force deployments could be found in a timely manner.

The next section of this paper explains why these two archived SPOT images were selected for further study. It also provides historical details on the composition and movements of the ground

forces that operated in the desert area shown in the two SPOT images. The third section details the analysis of the SPOT images. Using basic image enhancement techniques, the analysis revealed the changes that took place within the imaged area as a result of the troop deployments. The last section considers the significance of the results on the feasibility of using SPOT-type satellites to detect and track offensive attack preparations. The paper concludes with an assessment of the cooperative security implications associated with the future deployment of SPOT-type systems.

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Selection of the Study Area and SPOT Images

The 1991 Gulf War is an ideal real war situation for testing the SPOT satellite's ability to detect troop concentrations. The theater of operation contained a dense and varied array of multinational forces, including approximately 500,000 US personnel and an estimated 360,000 Iraqi troops. Further study of the 1991 Gulf War is also of interest because a comparable desert war could occur again in the future. Consequently, it is worthwhile to determine whether states in the Gulf region could use SPOT imagery to monitor troop activity within their geographic area of concern.

To test the SPOT sensor's troop detection capability, a study site had to be selected where there was a priori knowledge that massed troops had been deployed into the area and where there were archived SPOT images of that area. A literature review of available historical narratives came up with a US Army map that shows the approximate positions of the various elements of the multinational force. Figure 1 shows the forward deployment positions and attack maneuvers of the coalition ground forces relative to the major towns and villages in the area. The diagram also shows that the troop deployments in Saudi Arabia extended from the coastal town of Ad Dammam to Rafha — a 528 km front.

Standard SPOT panchromatic images cover a 60 x 60 km area at a ten meter ground resolution. Nine images adjacent to each other would have been required to image the entire front line. To monitor the battle front routinely, these nine images would have to have been reacquired, processed, and interpreted at periodic intervals in accordance with the maximum revisit frequency of the SPOT satellites.

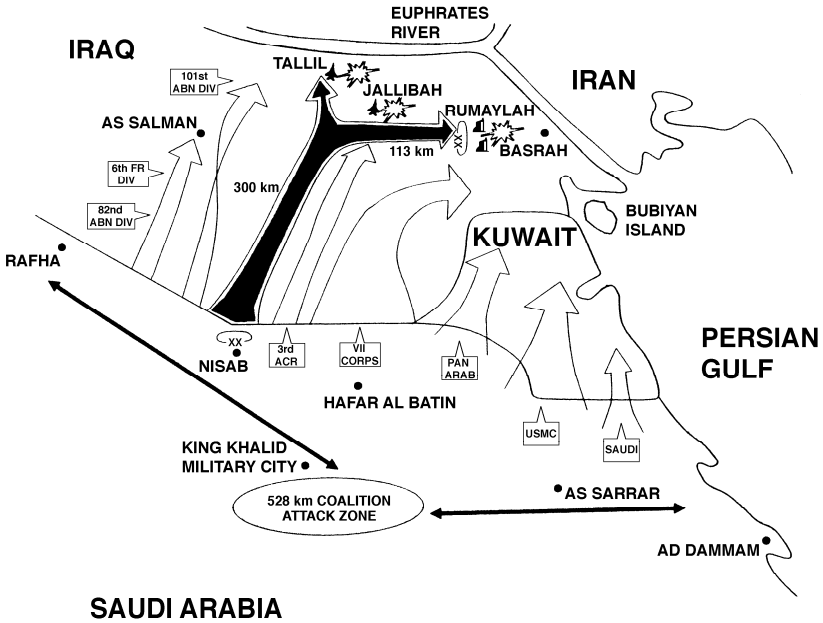

Figure 1: Forward deployment positions and attack maneuvers of the coalition ground forces. (Source: McCaffrey, "24th Infantry Division Ground Operations," p. 169).

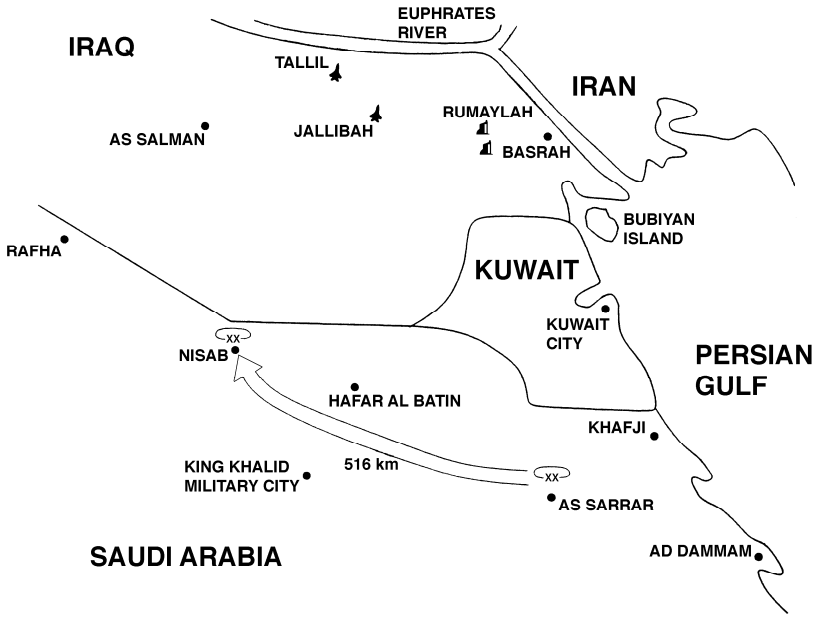

Figure 2: Deployment of the 24th Mechanized Infantry Division from its forward assembly area at As Sarrar to its pre-attack position at Nisab. Seventy five percent of the division's tentage was left behind at As Sarrar in order to enhance the division's attack mobility. Figure 1 shows the role the 24th played in the left hook maneuver. (Source: McCaffrey, "24th Infantry Division Ground Operations," p. 164).

To determine how the SPOT satellites were actually used during Operation Desert Shield and Operation Desert Storm, a list was compiled of all archived SPOT images of the Saudi-Iraqi and Saudi-Kuwaiti border acquired between 1 August 1990 and 1 March 1991. The list of available images was then compared with the troop positions shown in Figure 1.

Based on this comparison, the region around the town of Nisab was selected as the study area. Located along the Saudi-Iraqi border, this region was chosen because images of the area were available, and because it was the only mapped town where an entire division — the US 24th Mechanized Infantry Division — was deployed in close proximity (see Figure 1). As a result, the geographic coordinates of Nisab could be used to determine a priori exactly which SPOT images might show elements of the 24th. Two panchromatic images were selected for detailed analysis. One image was acquired on 20 August 1990 approximately three weeks after Iraq invaded Kuwait; the other image was acquired on 29 January 1991 almost two weeks after Operation Desert Storm began and four weeks before the start of the ground war. The 20 August 1990 image was acquired before the deployment of the 24th into Saudi Arabia, and the 29 January 1991 image was acquired one day after the 24th left most of its tentage at its forward assembly area at As Sarrar and completed its movement to pre-attack position near Nisab (see Figure 2). The division consisted of 25,000 soldiers in 34 battalions, 1793 armored vehicles, 6566 wheeled vehicles, and 94 helicopters.

Analysis of the SPOT Images

Prior to the interpretation of the imagery, both SPOT panchromatic images were contrast and edge enhanced in order to reveal subtle features that blended with the desert background. Each image was then searched for features associated with human activity; towns, trails, roads, and encampments were identified and mapped.

Figures 3 and 4 show the maps that were produced from the two SPOT images. These maps reveal dramatic changes that took place within the five month time period between the two image acquisitions. In Figure 3, the map shows two roads that run parallel with the Saudi-Iraqi border; one road lies on the Iraqi side and the other on the Saudi side. South of Nisab, the map shows numerous trails that converge at Ash Shubah town and connect with the paved Tapline Road — a road that runs parallel with an oil pipeline

shown in a UK MoD map. Since the historical archives indicate an absence of military activity in this area during August 1990, the trails were attributed to civilian traffic, specifically Bedouin Arabs traveling between Ash Shubah and the desert.

Approximately five months later during Operation Desert Storm, virtually all of the Bedouin trails connected to Ash Shubah disappeared and numerous new encampments were detected and located near the Tapline Road up to the Saudi-Iraqi border (see Figure 4). In addition, two new unpaved roads were found leading off the Tapline Road and heading north towards the border. Linking the only paved road with several smaller trails connected to the encampments, these two unpaved roads were inferred to be primary supply routes to the border.

Approximately thirty of the new encampments were concentrated near Ash Shubah town. Plates 1 and 2 are "before-after" SPOT enlargements of this area shown on 20 August 1990 and 29 January 1991. The "before" image clearly shows the Bedouin trails connected to Ash Shubah as well as the absence of large-scale human activity in the adjacent desert area. The "after" image shows new encampments near Ash Shubah.

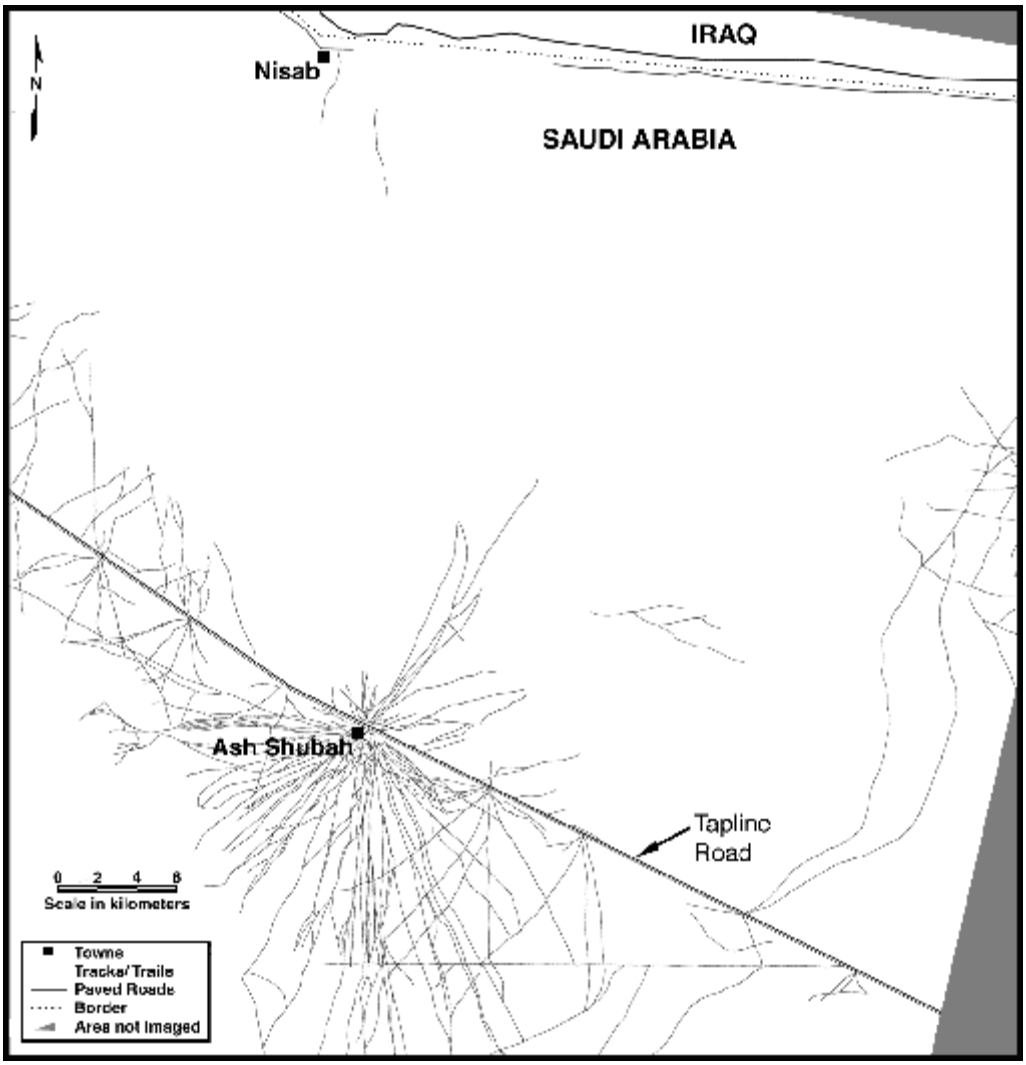

Figure 3: Map of features identified in the 20 August 1990 SPOT image along the Saudi-Iraqi border near the towns of Nisab and Ash Shubah. The image was acquired three weeks after Iraq invaded Kuwait when no coalition forces were present in this area. The shaded regions represent ground areas that were not imaged by the SPOT sensor.

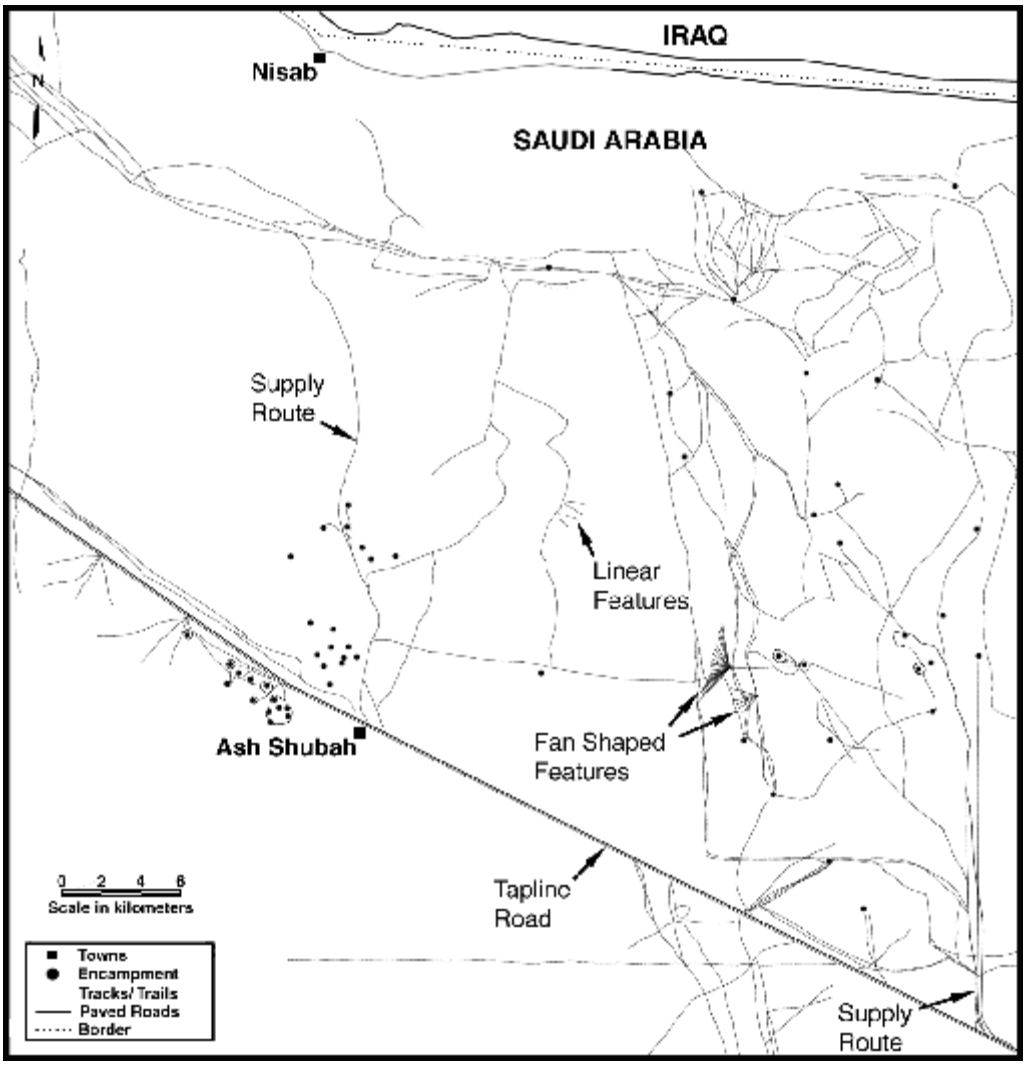

Figure 4: Map of features identified in the 29 January 1991 SPOT image covering the same ground area shown in Figure 3. The image was acquired one day after the US 24th Mechanized Infantry Division completed its deployment into the area.

South of the Tapline Road, each encampment is surrounded by berms for protection, and trails connect the encampments with each other. Inside each perimeter, there are several dark dots and polygons indicating the presence of large structures and vehicles. North of the main road, the encampments are peppered with numerous single pixel dots which suggest the deployment of small tents and vehicles.

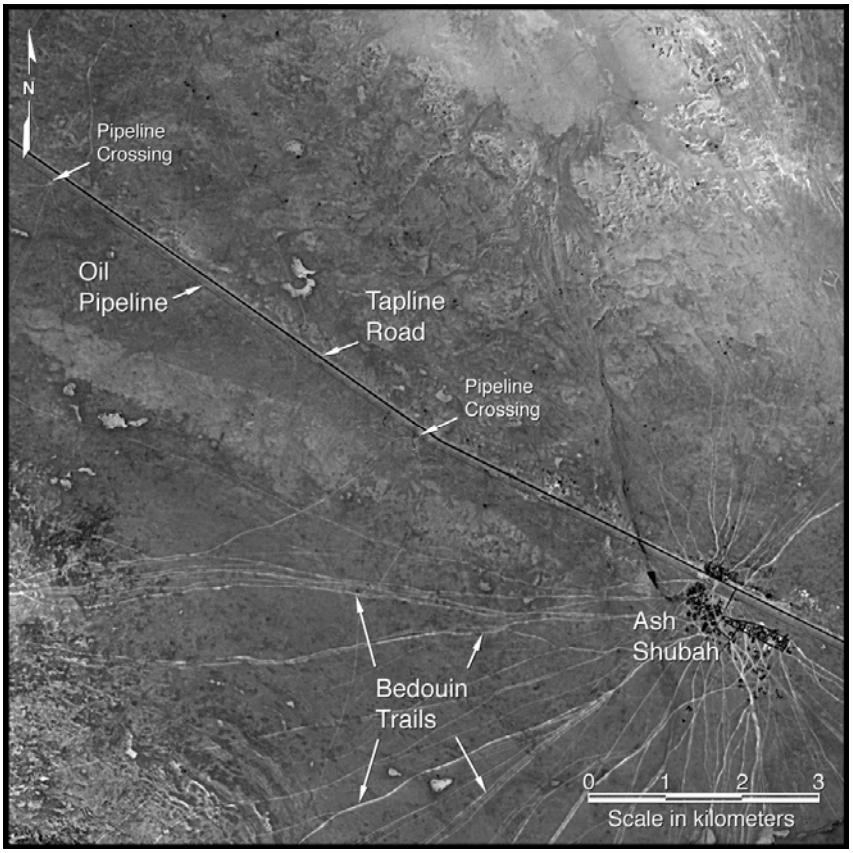

Plate 1: Enlargement of 20 August 1990 SPOT image around Ash Shubah town. This enhanced image clearly shows the town, Tapline Road, and oil pipeline. It also shows most of the Bedouin trails mapped in Figure 3.

Near Ash Shubah town, a new bypass road can be seen connecting the Tapline Road with one of the primary supply routes. The road appears to have been constructed in order to reduce the vehicle traffic running through the small town. Immediately south of the town, the "after" image shows that the Bedouin trails have been covered with sand, indicating the absence of civilian traffic between the town and desert (see Figure 3 and 4).

The cessation of civilian traffic was directly attributable to the military buildup. Personnel from the 24th Mech explained that most of the civilians felt uncomfortable with the substantially increased military presence so they left Ash Shubah as the ground forces moved into the area. The military encampments shown in Plate 2 were located within Division Support Area 1 (DSA 1) which consisted of the 260th combat support battalion, the 171st support regiment, and Division Support Command (DISCOM). Deployed along the Tapline Road and near one of two primary supply routes to the border, these forces played a critical role in supply (e.g., fuel, food, ammunition, medical, etc.) and maintenance (e.g., aircraft, vehicle, electronic, etc.).

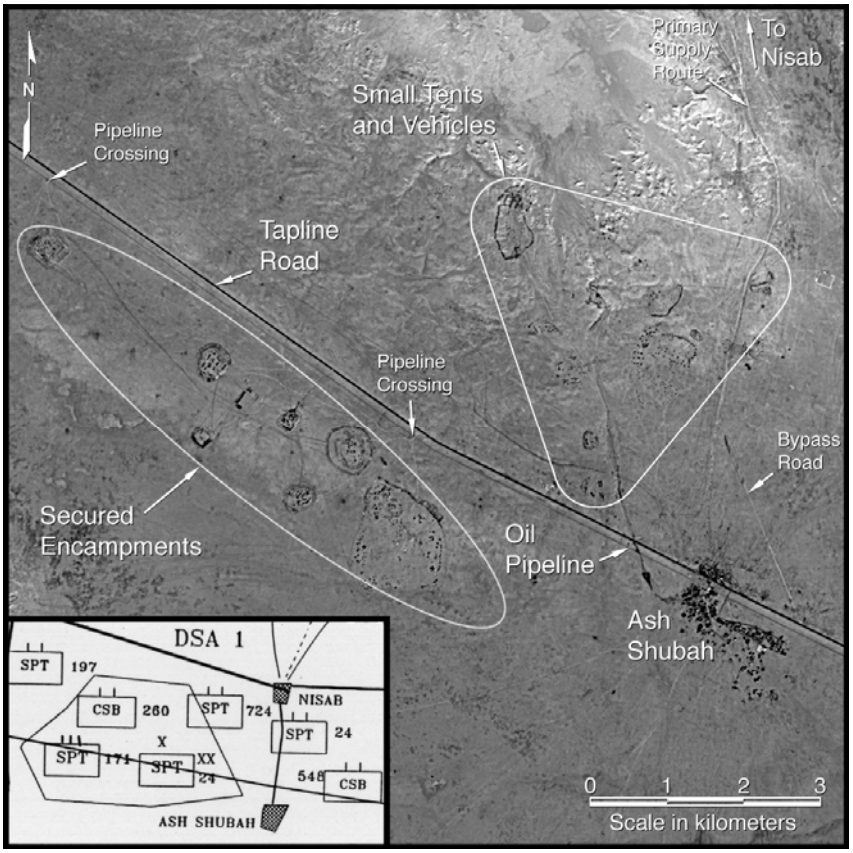

Plate 2: Enlargement of 29 January 1991 SPOT image around Ash Shubah town. Acquired two weeks after the initation of Operation Desert Storm, the image shows numerous new encampments west of Ash Shubah as well as several single pixel features which were inferred to be small tents and vehicles. The enlargement also shows a new primary supply route and bypass road. The inset is a map section from the historical archives that show the specific units that were deployed near Ash Shubah.

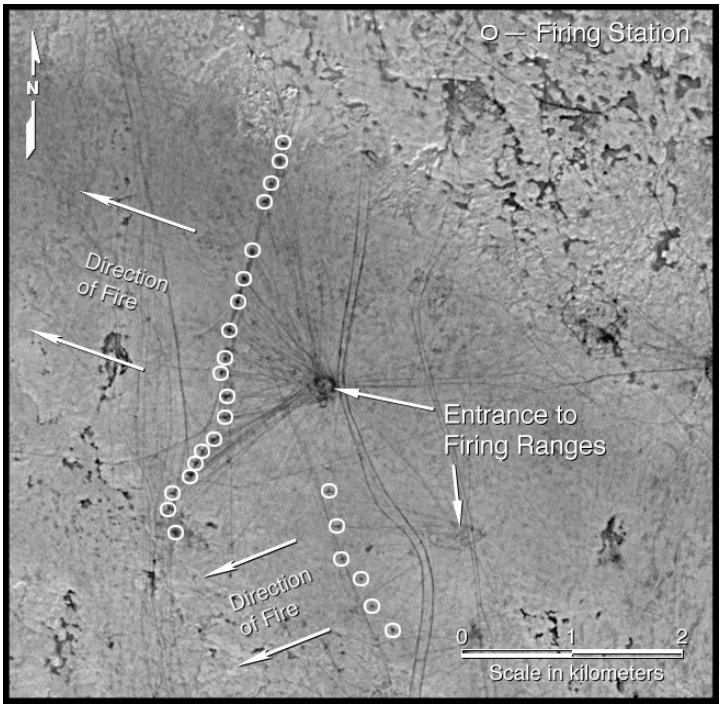

Plate 3: Enlargement of 29 January 1991 SPOT image showing two fan shaped features in the open desert (see Figure 4). Based on the layout and the trail patterns, the features were identified as firing ranges for mechanized units. The image shows the entrance at the central hub, the firing stations, and the direction of fire. The larger range could accommodate a mechanized company and the smaller range could accommodate a mechanized platoon.

In addition to the logistical infrastructure, the SPOT imagery also revealed two fan-shaped features that were not present in the "before" image. Located east of Ash Shubah (see Figure 4), the larger feature consisted of 19 endpoints connected to a central hub, and the smaller feature consisted of six endpoints connected to a different hub (see Plate 3). Isolated from the Tapline Road and the encampments, the features did not appear to be logistical in function. However, vehicular activity was apparent as indicated by the linear tracks between each endpoint and the respective central hub. There were also heavily used trails — as indicated by thickness — linking each hub to the trail network (see Plate 3 and Figure 4).

The trail configuration indicated that vehicles would enter or leave the area from one of the two central hubs. The tracks forming the fan shape indicated that the vehicles would either scatter from the hub to the multiple endpoints or converge from the endpoints to the central hub. This layout ultimately revealed the purpose of the two features — firing ranges for mechanized units. The larger range could accommodate a mechanized company and the smaller range could accommodate a mechanized platoon.

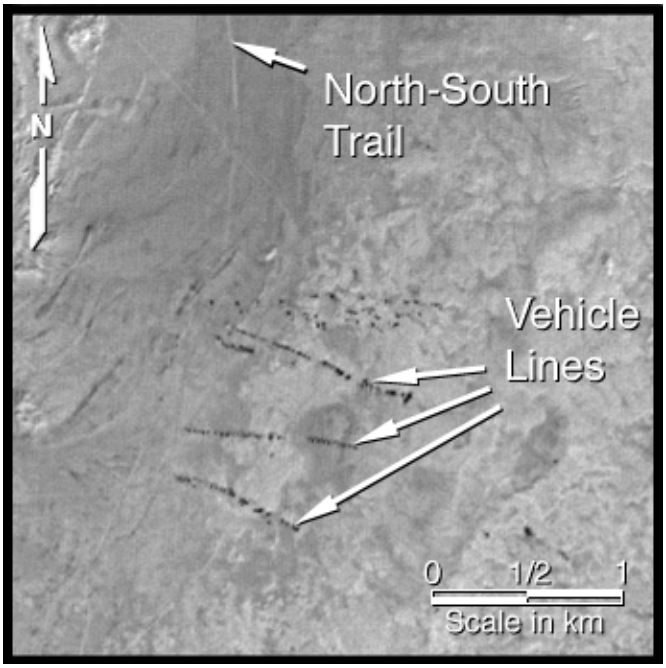

Plate 4: Enlargement of 29 January 1991 SPOT image showing linear traces next to a north-south trail (see Figure 4). The trace configuration is consistent with the appearance of vehicle lines positioned close together for protection, line-of-sight communication, and possible forward attack advancement.

Set up for field trained, the firing ranges would receive the mechanized units at the central hub which served as the range control. The troops would be assigned their firing station there. They would then deploy their vehicles to the designated position, and fire their weapons into the open desert away from the central hub (see Plate 3). After the target practice was completed, the units would rendezvous at range control and redeploy to their assigned position.

Plate 4 shows one troop position near the firing range. The enlargement shows a series of linear traces that were not present in the "before" image (see Plate 4). Deployed next to a north-south trail route (see Figure 4), the traces consist of numerous single pixel objects positioned close together. The layout is consistent with the deployment of tracked or wheeled vehicles positioned closely for imminent convoy operations, line-of-sight communication, and rudimentary protection.

Implications and Conclusions

The analysis of the SPOT imagery produced several significant results. It demonstrated empirically that medium resolution imagery can be used to detect, locate, and identify troop encampments in desert terrain despite the fact that individual soldiers and vehicles cannot be resolved. The positive identification of troop positions was facilitated by the dramatic appearance of numerous secured encampments and the sudden disappearance of normal civilian traffic (see Figures 3 and 4). The observation of the new, redundant trail network further suggested that the new inhabitants in the area were indeed military forces (see Figures 3 and 4). After these forces were found, more detailed analysis revealed the logistical areas, training grounds, and troop positions (see Plates 1-4). Each feature was identified from its topographic location, layout, configuration, and associated level of activity.

Although the ability to find massed troops in the desert at medium spatial resolution proved to be impressive, it was tempered by one key limiting factor. Because the spatial detail within the

imagery was relatively coarse, it was not possible to identify the specific military units using only the image information; while it was often possible to infer the function of the units from the images, the historical archive contained the only open source information on the exact composition of the deployed force. Consequently, it would have been difficult to gauge the strength and readiness of the observed military forces accurately using the SPOT satellite imagery alone.

In addition to providing new facts and insights on the 24th Mech operations during the 1991 Gulf War, the results from this study demonstrated how SPOT-type systems could track future troop movements in desert terrain. Table 1 lists all deployed satellites with SPOT-type sensors and planned satellites with SPOT-type sensors scheduled for launch by the year 2000. All of these satellites are capable of providing timely broad swath, medium resolution information to detect the massing of conventional offensive forces in desert terrain and infer the basic function of the various imaged units.

Satellite	Country	Resolution of SPOT-type sensor	Swath Width	Launch Date
SPOT 1-4	France	10 meter panchromatic	120 km*	1986, 1990, 1993, 1998
COSMOS series TK-350	Russia	10 meter panchromatic	300 km	1987-1998
IRS-1C, IRS-1D	India	6 meter panchromatic	141 km*	1995, 1997
Priroda	Germany Russia	6 meter panchromatic	40, 80 km	1996
ADEOS	Japan	8 meter panchromatic	80 km	1996
OrbView 3	USA	8 meter hyperspectral	5 km	1998
KOMPSAT	S. Korea	10 meter panchromatic	40 km	1999
RESOURCE21	USA	10 meter panchromatic	205 km	2000
ALOS	Japan	10 meter multispectral	70 km	2000

* – wide swath obtained by using multiple side-by-side sensors simultaneously

Table 1: Deployed and planned commercial satellites with SPOT-type sensors (i.e. broad swath, medium resolution) on board.

This fleet of commercial satellites can be a troop monitoring resource for all Middle East, African, and Asian states that contain or border desert terrain. These states could apply this technology for early warning and verification purposes. Along international borders and demarcation lines, states could conduct routine overhead searches for the telltale signs associated with a conventional invasion force. In existing and proposed demilitarized zones, states could use commercial satellite imagery to verify the absence of battalion-sized military units.

Both the early warning and verification missions could be done with a high level of assurance that any threatening troop activity would be found in a timely manner. With twelve or more different commercial satellites equipped with SPOT-type sensors, states could tap a wealth of imagery to scan the desert with the reassuring knowledge that any offensive force would require at least a week to deploy into position, have little cloud or natural cover to rely on for concealment, and rely heavily on observable logistics trails for basic sustenance (eg fuel, food, water).

While the technological improvements in satellite imaging and the operational realities associated with desert warfare make it possible to find troop concentrations, the effectiveness of troop monitoring ultimately depends on the efficiency of the organization that performs the task. Since a sudden, massed deployment of troops would most likely represent a grave threat to one or more states, the monitoring organization must be capable of detecting troop movements quickly to allow maximum time for diplomatic and military efforts to diffuse the situation. Whether the organization operates independently at the national level or cooperatively at a regional or international level, it must have the technical capability to collect, process, and interpret the commercial satellite imagery within a 48-72 hour time frame. In addition, it must have the technical capability to disseminate the interpreted imagery in near real-time to other states and institutions — including adversaries — that may have an interest in the information. Within a cooperative monitoring regime, this process can be facilitated by establishing a remote sensing center staffed by representatives from all state-parties of the regime. Such a center could enable the state-parties to identify false alarms quickly and address questionable or suspicious activity immediately after it was identified.

The use of commercial SPOT-type satellites for routine troop monitoring is a relatively new application. This study has empirically demonstrated the technical feasibility of the application in one environment, and explored the associated opportunities. Future research should examine the use of SPOT-type satellites for troop monitoring in different environments (eg mountains, forests, tropical islands), and devise diplomatic and military strategies for adapting to these recent remote sensing developments. There are innovative ways for diplomats and technologists to use SPOT-type sensors in a cooperative mode to enhance state security, and there are creative approaches for soldiers to use the same sensors in a hostile mode for targeting ground forces. Both scenarios are realistic possibilities for the future. Thus, the challenge for all actors involved in conflict prevention and resolution will be to formulate prudent policies to increase the use of SPOT-type sensors for facilitating and maintaining peace in historically hostile regions.

Content: Vipin Gupta