RevMexAA (Serie de Conferencias), **31**, 120–132 (2007)

RECONNAISSANCE FIELD REPORT FOR THE SEARCH OF LARGE TELESCOPE SITES IN THE SIERRA SAN PEDRO MARTIR, BAJA CALIFORNIA, MEXICO

Erika Sohn[1]

RESUMEN

La Sierra San Pedro Mártir en el estado de Baja California, México, es conocida por sus excelentes condiciones para la observación astronómica. Ofrece una serie de sitios con elevaciones que rebasan los 2650 m, potencialmente apropiados para la instalación de futuros grandes telescopios. Algunos de estos sitios son remotos y es necesario determinar sus rutas de acceso para efectuar mediciones de evaluación de las condiciones para la observación astronómica. Durante el verano de 2005 se visitaron seis sitios que pueden ser adecuados para la instalación de telescopios e instrumentos de medición de la calidad del cielo, para determinar sus coordenadas así como sus posibles rutas de acceso. En este trabajo se presenta una breve descripción de cada uno de estos sitios.

ABSTRACT

The Sierra San Pedro Mártir in the state of Baja California, Mexico, is known for its excellent conditions for astronomical observations. It offers a series of potential locations, with altitudes above 2650 m for the installation of large telescopes. Some sites are quite remote and adequate site evaluation access routes have to be devised. Six potential sites were visited in summer 2005 either by foot or using a 4WD vehicle in order to search for suitable places for the installation of large telescopes and site evaluation access routes. GPS coordinates were obtained and possible access routes were devised. Photographs, a brief description of each zone, observed rocks as well as general comments are presented.

Key Words: **SITE TESTING**

1. INTRODUCTION

The Observatorio Astronómico Nacional (OAN), under custody of the Universidad Nacional Autónoma de México, has been successfully operating at the Sierra San Pedro Mártir, in northern Mexico, for nearly 30 years. It has proven to be one of the best sites for astronomical observations in the Northern Hemisphere (Cruz-González, Avila, & Tapia 2003) and is a potential site for the installation of future large telescope facilities. The present work describes a reconnoitering field trip during which a series of potential sites for the installation of astronomical observing facilities were explored.

1.1. *Location and description of Sierra SPM /OAN*

The Sierra San Pedro Mártir (SPM) is located in the northern-central part (31°N), approximately 50 km inland, of the Baja California Peninsula in Mexico. It is a high mountain range that climbs gently eastwards from the Pacific Ocean to about 3100 m and drops abruptly along the SPM escarpment to an elevation of roughly 600 m to an alluvial desert westward, off the coast of the Gulf of California. It covers an area of 342,801 ha. The Sierra San Pedro Mártir National Park is one of the few Mediterranean-climate forests in Mexico. It represents a "sky island" (Phillips & Wentworth 2001); an elevated and isolated pine-oak forest surrounded by chaparral and desert that prevents species migration and causes this ecosystem to be unique. SPM presents a high biodiversity; it is home to many endemic and endangered species: 5 mammal species and 3 subspecies, at least 20 endemic plant species/subspecies and 20 bird species, among which, the recently reintroduced California condor can be counted. The Observatorio Astronómico Nacional (OAN) is located close to the mountain range escarpment at an average altitude of 2800 m. It is located within the "Parque Nacional Sierra San Pedro Mártir" national park, a protected 63,000 ha area. Table 1 enlists the national park boundary coordinates, whereas Table 2 enlists the coordinates corresponding to the area assigned for astronomical observations. Figure 1 depicts a height-coded Landsat 7 image outlining the areas corresponding to the national park boundaries

[1]Instituto de Astronomía, Universidad Nacional Autónoma de México, Apdo. Postal 70-264, México, 04510 D. F., México (sohn@astroscu.unam.mx).

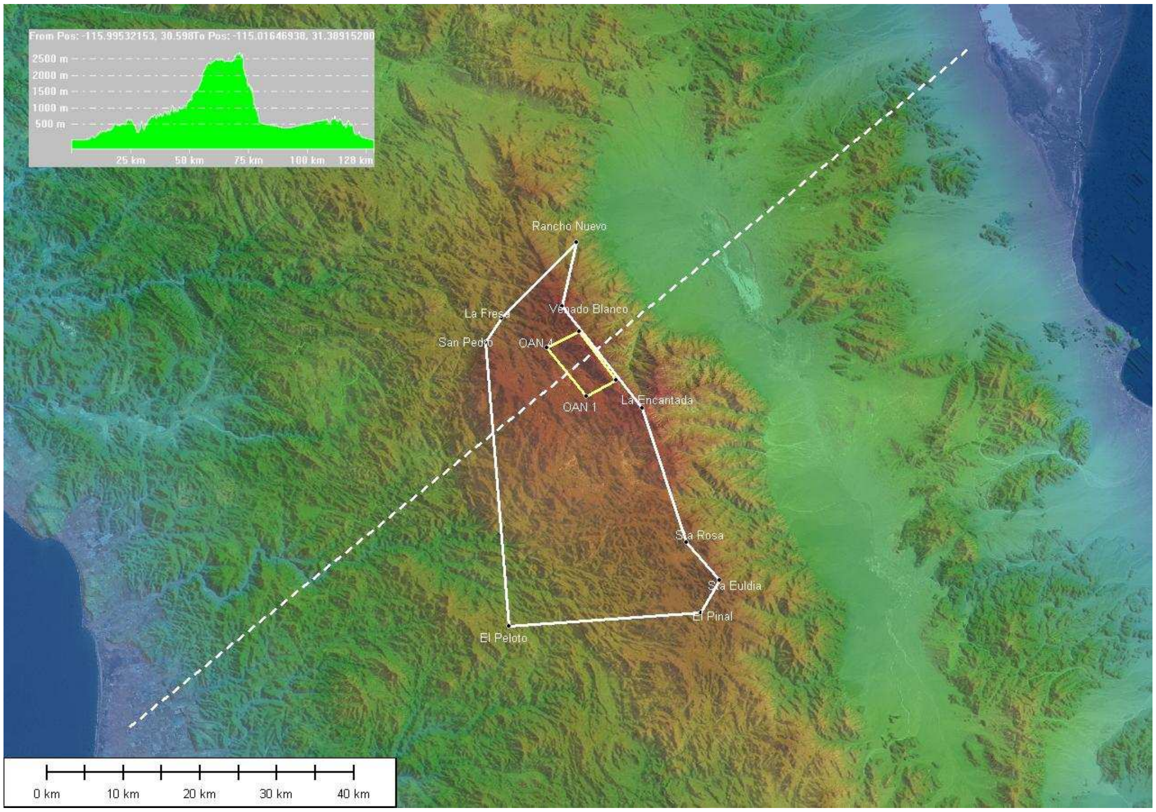

Fig. 1. Height-coded Landsat photograph of a northern portion of the Baja California Peninsula containing the Sierra San Pedro Mártir National Park. The larger irregular polygon (white) represents the National Park boundaries, whereas the smaller rectangle (yellow) represents the area assigned for astronomical use. A cross section along the broken line (SW-NE) is shown in the upper left. The Pacific Ocean is to the left whereas the Gulf of California is to the right of the figure. North is up.

TABLE 1

SPM NATIONAL PARK BOUNDARIES

Waypoint name	Easting	Northing
Cerro el Peloto	11 R 638950	3398925
Cerro el Pinal	11 R 660350	3401000
Cerro la Encantada	11 R 653400	3427325
Cerro Santa Euldia	11 R 662400	3405170
Cerro Santa Rosa	11 R 658575	3410050
La Fresa	11 R 637613	3438792
Rancho Nuevo	11 R 646210	3447181
San Pedro	11 R 635712	3435753
Venado Blanco	11 R 644248	3440554

(yellow polygon) and the area assigned for astronomical exploitation (white rectangle). A section across the peninsula (pink line) is shown on the upper left of the figure.

TABLE 2

POLYGON ASSIGNED
FOR OBSERVATORY USE

Waypoint name	Easting	Northing
OAN 1	11 R 647162	3428815
OAN 2	11 R 650413	3430931
OAN 3	11 R 646285	3437176
OAN 4	11 R 642672	3435008

1.2. *Geological setting*

The observatory is located atop the edge of the San Pedro Mártir pluton, a Mesozoic granitic body, which is part of the Peninsular Ranges batholith, spanning for about 1600 km and exposed from southern California (34°N) to northern Baja California (28°N) (Barajas & Argote 1995). The Peninsular Ranges batholith has been divided into western and

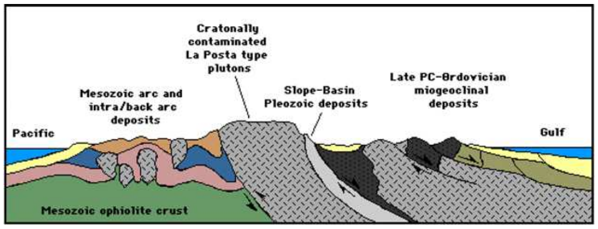

Fig. 2. Profile across northern Baja California (from Gastil 1993). The described sites are located at the eastern edge of the La Posta type pluton with the exception of the Punta San Pedro Mártir site which is located on the NW edge of the SPM pluton.

eastern (La Posta) zones on the basis of geochemical, geophysical and lithological relationships (Walawender et al. 1990). The SPM pluton corresponds to the eastern (younger) zone and ranges concentrically in composition from tonalite to granodiorite. It was emplaced during a prolonged and continuous period of magmatic activity during the Cretaceous (120-90 Ma) along the boundary of the metavolcanic arc terrane of the Albian Alisitos Group to the west and metasedimentary and metaplutonic rocks of uncertain Cretaceous age to the east. The Sierra SPM pluton was emplaced at a depth between 12 and 20 km and has since been uplifted, eroded ca. 7 km and tilted approximately 15° (Ortega-Rivera et al. 1997). The metamorphic grade of the country rock increases from west to east (Gastil 1993). Figure 2 shows a schematic section across the peninsula at the location of Sierra SPM. The 2-m site is located atop a massive quartz, feldspar and muscovite pegmatitic dike with large (ca. 10 cm) crystals. The surrounding country rock is a biotite, muscovite and quartz schist. Two of the sites described in this work (Antenas and Meseta) are situated on this rock type (CFE 2001). The rest are located on the SPM pluton.

1.3. *Software / Hardware*

This field trip relied on two GPS receivers: a Garmin GPSMAP 276C (version 2.5) and a Garmin eTrex VistaCx (version 3.3) receiver. Both units are 12-channel, parallel, WAAS-enabled devices with a 1:250,000 Baja California basemap (Baja Expeditioner Map). The maps covering the visited area are INEGI 1:50,000 topographic maps: H11B55, Santa Cruz and H11B45 San Rafael. Datums used for this report are WGS84. All coordinates are in UTM. A map by Jerry Schad (Centra publications) Parque Nacional Sierra San Pedro Mártir was used during the field trip to locate trails not marked in the INEGI maps. Geologic maps CETENAL H11B45 and H11B55 as well as geologic maps by Gastil et al. (1971) were used in order to identify the geologic setting of the region of interest. The figures generated for this report used the following GPS mapping and navigation software. Maps: INEGI H11B45 (San Rafael) and INEGI H11B55 (Santa Cruz) raster and vector maps, INEGI Orthophotographs. NASA LANDSAT digital imagery and Digital Terrain Elevation Data. Software: Global Mapper, OziExplorer, Arcview, Google Earth and NASA Worldwind.

TABLE 3

COORDINATES OF 2-m TELESCOPE

Site	Easting	Northing	Altitude
2M	11R 646662	3435317	2818 m

TABLE 4

MESETA SITE COORDINATES

Name	Easting	Northing	Altitude
Norte	11R 645844	3436392	2685 m
Mesa E2	11R 646239	3434781	2694 m
Barrack	11R 646195	3435026	2703 m
Mesa Salida	11R 646125	3435046	2707 m
Mesa E3	11R 646364	3434946	2712 m

2. SPM POTENTIAL SITES

The area assigned for astronomical use is located along the edge of the Sierra SPM escarpment (Figure 3). Several sites suitable for the installation of large telescopes can be found along this ridge. The criteria used for the selection of the sites were altitudes above 2650 m and relatively easy access from the observatory facility. Two of the sites are remote with no current access routes but with high elevations. A total of six sites were explored, ordered in terms of current accessibility: La Meseta, Cerro de las Antenas, El Altar, Punta San Pedro Mártir, Venado Blanco and Cerro Botella Azul. Figure 4 shows the location of all sites reported in this work on a height-coded orthophotograph. Some of the sites were arbitrarily named since no information exists concerning their names (Cerro de las Antenas, Meseta). For reference, the 2-m telescope coordinates are listed in Table 3.

2.1. *La Meseta*

The Meseta site (Figure 5) is located close to the living quarters and next to the observatory road. It

Fig. 3. (a) View from the Laguna del Diablo desert (600 m) towards the Sierra San Pedro Mártir escarpment (2800 m), right. The large mountain to the left is Picacho del Diablo (3100 m). The visited sites are along the SPM escarpment (center-right) and are identified on the vertically exaggerated NASA Worldwind 3D image to the left. (b) Photograph of SPM escarpment taken from the East (Laguna del Diablo).

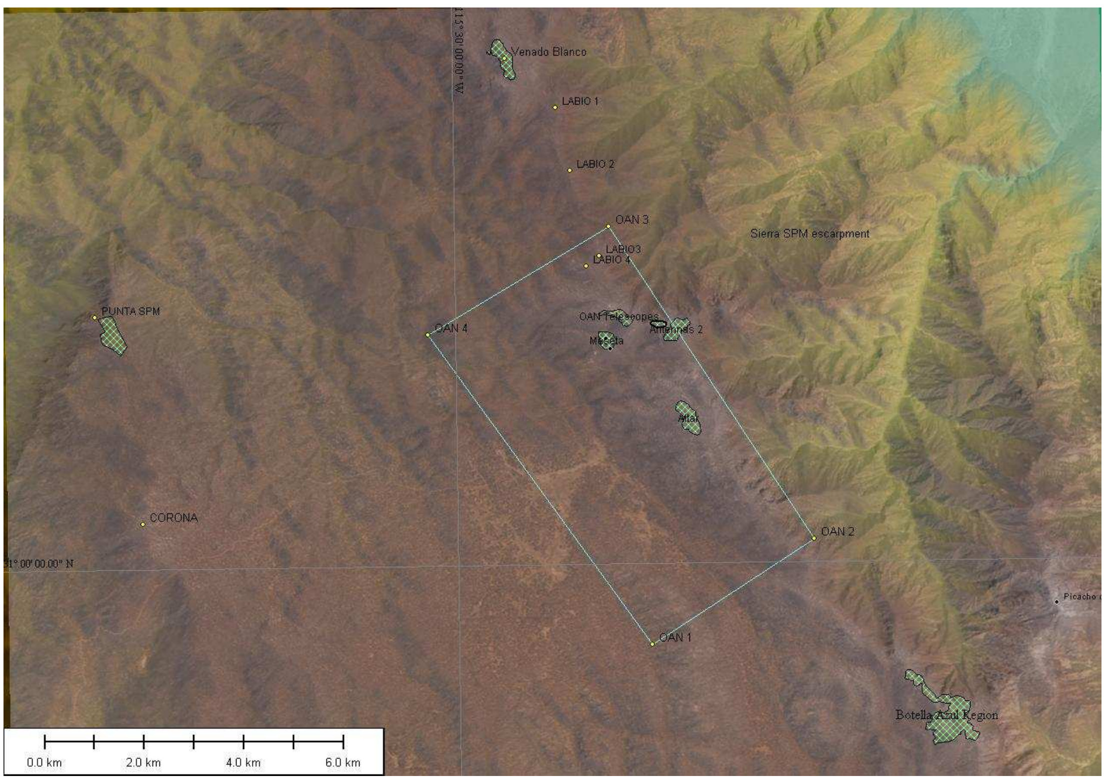

Fig. 4. View of all the visited locations. Several other potential sites not described in this work are indicated. The area assigned for astronomical observations is marked as a blue rectangle. Note that several sites are outside this boundary (waypoints OAN 1-4). North is up.

is located on a protruding side of a hill approximately facing west. The average altitude is 2690 m. The site is quite level, with a slight slope downwards towards the SW. It covers an area of approximately 9.65 ha, enclosed by a 1.16 km perimeter. Table 4 enlists coordinates taken at this site. There is relatively high tree coverage and the rock type is a biotite, muscovite and quartz schist. Currently there is a shack on the site. It is readily accessible with any vehicle and already and has access to the power grid.

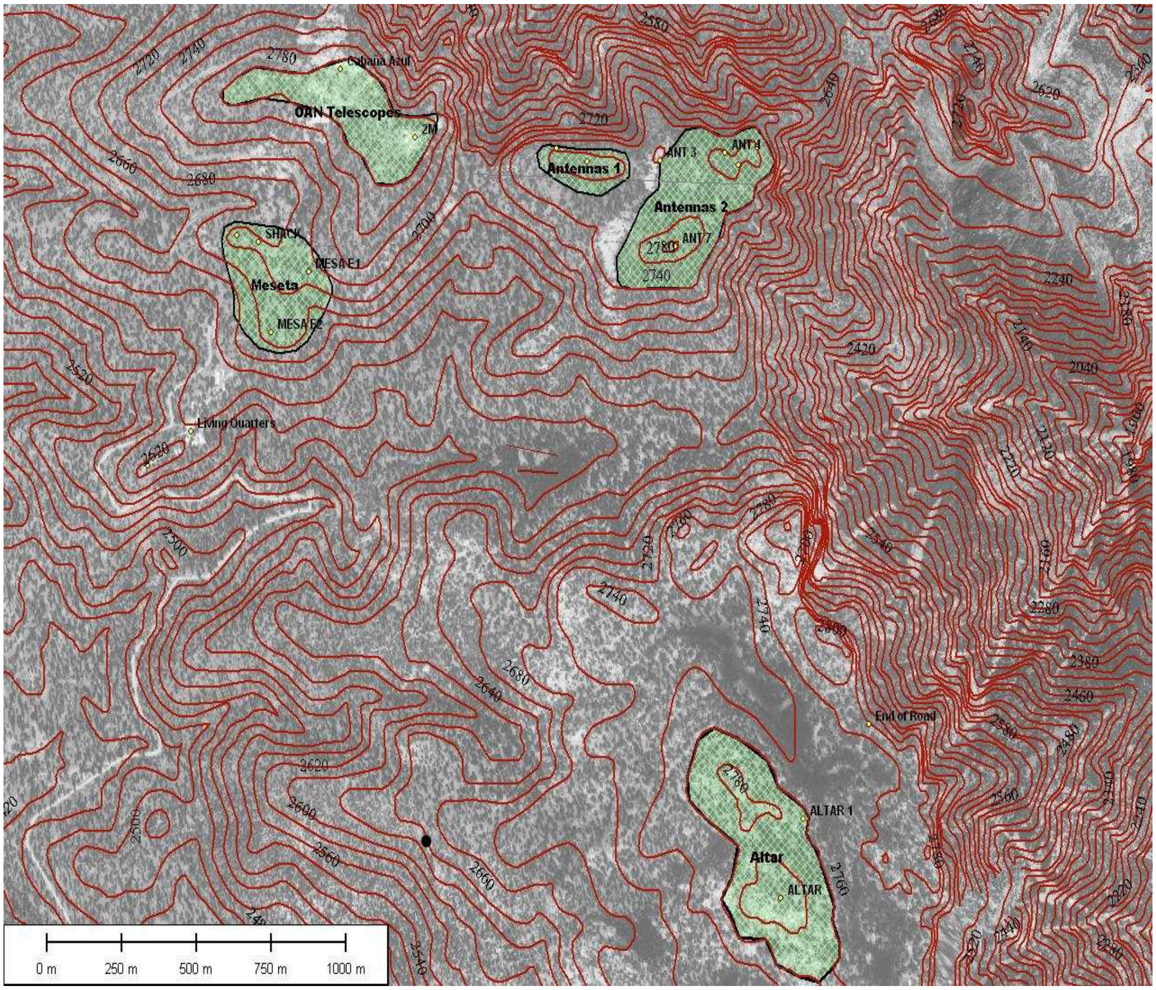

Fig. 5. Topographic map showing the location of the Meseta, 2-m telescope, Antennas and Altar sites. The observatory road, living quarters and OAN telescopes site are also included. Distance between elevation lines is 20 m. North is up.

The horizon is clear with the exception of part of the 2 m hill which obstructs the view towards the NE. Figure 6 shows an elevation profile across points Mes and Mes*. The photograph to the left shows a view from the NE of the Antenas site. Note the flat profile of this hill.

2.2. *Cerro de las Antenas*

The Cerro de las Antenas site is located on a hill about 600 m east of the 2 m building. At the time of the field trip, several abandoned repeater antennas littered the site but have since been removed. It is a wide and relatively level plateau (Figure 6a) where two usable areas can be identified: Antennas 1 and Antennas 2, the former is a 3.06 ha area enclosed by a 745 m perimeter, whereas the latter is a 13.6 ha area enclosed by a 1582 m perimeter. Figure 7 shows a closeup of the Meseta and Antennas

TABLE 5

CERRO LAS ANTENAS WAYPOINTS

Name	Easting	Northing	Altitude
ANT 1	11R 647192	3435283	2791 m
ANT 2	11R 647294	3435247	2780 m
ANT 3	11R 647538	3435251	2785 m
ANT 4	11R 647753	3435271	2796 m
ANT 5	11R 647864	3435286	2798 m
ANT 6	11R 647801	3435239	2790 m
ANT 7	11R 647589	3435016	2770 m

sites. Figure 9 shows cross sections along the Antennas 1 (Ant1-Ant* line, left) and Antennas 2 (Ant2-Ant2* line, right) sites. As of this writing, a 4WD access route has been made and both areas can be

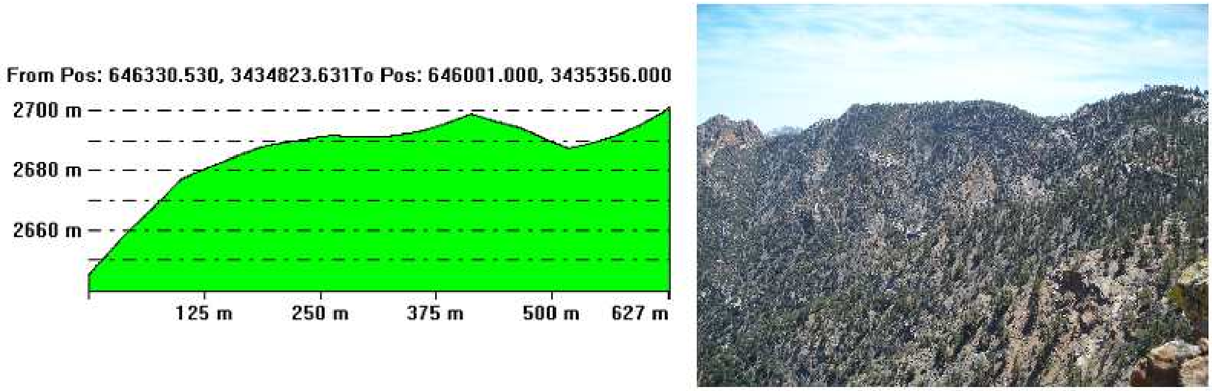

Fig. 6. (a) Elevation profile of the Meseta site. (b)View from the NE of the Cerro de las Antenas. Note the flat profile of this site. The 2-m telescope can be seen to the right. The entire zone is composed of schist.

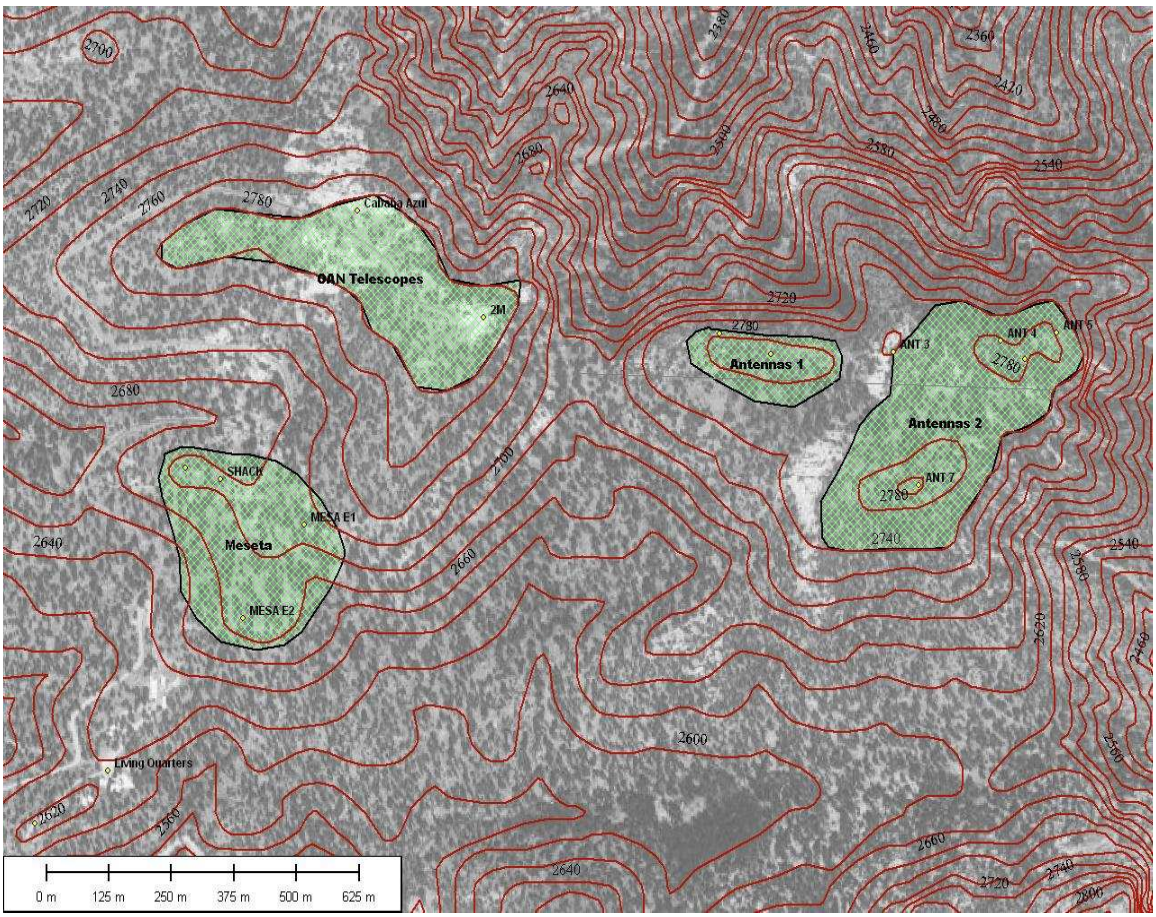

Fig. 7. Map of the Meseta, 2 m telescope and Cerro de las Antenas sites. Height increments are 20 m. North is up.

easily reached. Site testing is already under way at these sites. The average altitude, 2760 m, is slightly lower than the 2-m site (2818 m). The eastern ridge presents a boat keel geometry that drops abruptly into a gully. These sites present a clear horizon with 360° views of the surroundings. Both sites are atop a large muscovite bitotite and quartz schist promontory and are separated by a large pegmatitic dike.

TABLE 6

ALTAR SITE WAYPOINTS

Name	Easting	Northing	Altitude
End of Road	11R 648234	3433711	2770 m
Altar 1	11R 648016	3433452	2781 m
Altar 2	11R 647941	3433234	2793 m

Figure 8a shows a view of the boat keel site (ANT 5). Figure 10 shows a 340° view from the ANT 5 waypoint. Table 5 lists waypoint coordinates along the ridge and at central parts of these areas. As can be seen, tree coverage is relatively low.

2.3. *El Altar*

The Altar site is about 1 km E from the 2 m site and about 400 m from the Cerro de las Antenas. A 4WD road reaches a scenic lookout with a view towards the Desierto de Altar in Sonora. An elusive site testing access road has been made to this site. The Altar is located on a NW facing, relatively flat ridge, close to the SPM escarpment. It covers an approximate area of 18.8 ha, enclosed by a 1.96 km perimeter. The average altitude is approximately 2770 m, although a 100 m wide plateau has altitudes above 2785 m as can be seen in the cross section (AltAlt*) in Figure 11a. Figure 12a shows a view facing the Picacho del Diablo (left) and the Altar site plateu. As can be seen from the picture, the site is quite level and has a relatively low tree coverage. Figure 12b shows a photograph taken from the Altar 1 waypoint. The 2-m telescope, Cerro de las Antenas and Cerro La Corona can be seen in the background. Note the sparse tree growth and the granite boulders that cover the entire area. The Altar area corresponds to the edge of the SPM pluton. Table 6 lists some waypoints taken at the Altar site. The end of the 4WD road is also included.

2.4. *Punta San Pedro Mártir*

The Punta San Pedro Mártir site is located on the western edge of the SPM pluton. It is about 10.7 km from the 2-m site. It is the only site described facing west towards the Pacific Ocean at the edge of a steep wall. The average altitude is 2400 m, although the La Corona hill reaches 2600 m. The site is readily accessible and is close to the condor program living quarters and bird pens. It has a clear view of the western horizon and tree coverage is sparse. A disadvantage of this place is its apparent vulnerability to forest fires. Some large thermal currents must be present since it is the place where young condors

Fig. 8. (a) View of the ANT 5 site. The rock composition of this site is a biotite, muscovite and quartz schist. (b) View of Punta San Pedro Mártir. (c) View towards Sierra La Corona from Venado Blanco southern summit. (d) South View of Botella Azul.

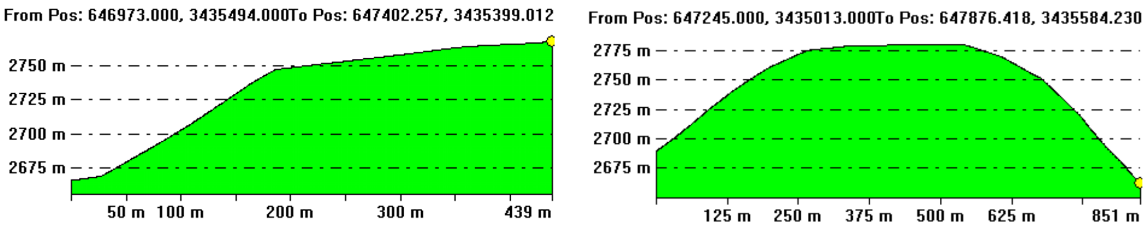

Fig. 9. Elevation profiles of Antenas 1 (left) and Antenas 2 (right) sites.

Fig. 10. 340° view from Antenas site (ANT 5 waypoint). (a-d) Note the unobstructed horizon. Most sites along the SPM escarpment have similar views of the horizon.

learn to fly. Table 7 shows some waypoints taken at this site. The Cerro La Corona waypoint is also included. Figures 8a and 8b show a view of the Punta San Pedro Mártir site.

2.5. *Venado Blanco*

The Venado Blanco summit site is a granite, boulder-strewn hill located on a narrow, elongated

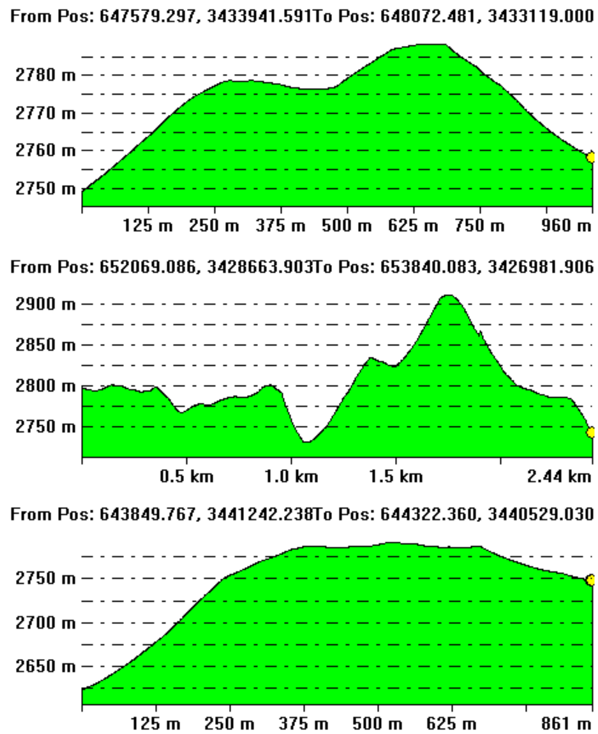

Fig. 11. (a) Elevation profile of the Altar site along the AltAlt* line. (b) Elevation profile along the Baz-Baz* line, at the Botella Azul site. (c) Cross section along the Venado Blanco hill.

TABLE 7

PUNTA SAN PEDRO MARTIR WAYPOINTS

Name	Easting	Northing	Altitude
Punta SPM	11R 635992	3435359	2398 m
Vista Condo	11R 636054	3434984	2409 m
Camp Botaz	11R 648113	3430275	2429 m
La Corona	11R 636956	3431205	2600 m

W-NW trending, 400 m long, 50 m wide ridge, close to the northern SPM escarpment. The granite presents spheroidal weathering and the site would have to be leveled several meters to be useful for the installation of a telescope. The average altitude is 2810 m (Figure 11c). The Venado blanco summit hill runs parallel to the SPM ridge. The distance to this ridge is approximately 700 m. The horizon is entirely unobstructed. Currently the access to this site requires a 3–4 hour, one way hiking time from the observatory. No readily access routes exist and no marked trails were found. Two possible access routes can be taken (cf. Figure 13): a 7 km long dirt road marked Venado Blanco that parts from the observatory road (campamento forestal) close to the living quarters and reaches a cabin by a creek. From there no marked trail was found and some serious bushwhacking, rock scrambling and about 2.5 hours were necessary to reach the site (not recommended). The other, easier route is along the edge of the escarpment, north of the 2-m site. This unmarked route reaches several other potential sites along the SPM ridge (Labio 1, Labio 2, Labio 3 and Labio 4) which should be taken into account for site testing runs, given their altitude and distance to the observatory. The ridge route to Venado Blanco is the most suitable for future road work since the terrain is relatively smooth and not too rocky. Figure 12c shows a view from the Venado Blanco southern summit along the SPM ridge where some of the potential sites were marked. Table 8 shows some waypoints taken at the Venado blanco site as well as these additional sites. Figures 8b and 8c show a view towards La Corona from the Venado Blanco summit. Note the schist that dominates the entire ridge, representing the country rock which the pluton intruded. The contact between both rock types is at the base of the Venado Blanco hill.

TABLE 8

VENADO BLANCO WAYPOINTS[a]

Name	Easting	Northing	Altitude
Venado S.[b]	11R 644248	3440554	2810 m
Venado	11R 644285	3439609	2745 m
Cabin	11R 642796	3437926	2265 m
Labio 1	11R 645213	3439562	2665 m
Labio 2	11R 645213	3438293	2682 m
Labio 3	11R 646099	3436599	2265 m
Labio 4	11R 645844	3436391	2685 m

[a]Note the additional possible potential sites: Labio 1 and Labio 4.

[b]Summit.

2.6. *Botella Azul*

The Botella Azul or Cerro La Encantada site is located on the eastern ridge of the SPM escarpment, south of the 2-m site. It faces the Picacho del Diablo peak (3100 m) and is the second highest peak in Baja California (2950 m). The potentially useful area for the installation of astronomical facilities is on an approximately 2 km long ridge ranging from Scout Peak (2850 m) to Botella Azul (Figure 14), with unobstructed views of the horizon. The enclosed area

Fig. 12. Altar site seen from the hill above the Altar lookout. Note the level plateau at about 2787 m. (a) The Picacho del Diablo can be seen in the background. (b) View from the Altar site. Sierra La Corona, the 2-m, as well as the Cerro de las Antenas sites can be seen along the horizon. (c) View of the San Pedro Mártir Ridge from the Venado Blanco southern summit. Two other possible sites can be seen along this ridge. The 2-m telescope can be seen in the background.

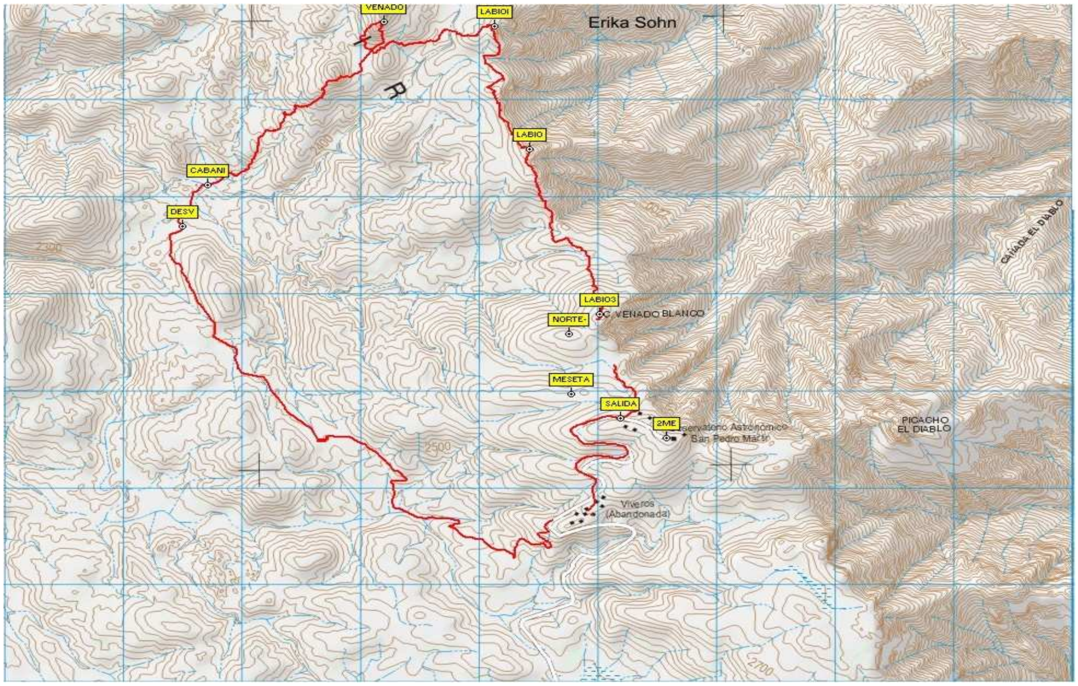

Fig. 13. Approach routes for the Venado Blanco site. The first route (western access) is a dirt road that reaches an abandoned cabin (Cabani). From there a rough approach is necessary. The route along the ridge (eastern route) passes several other possible sites and is relatively feasible for future road work. Both routes take approach times in excess of four hours (on foot).

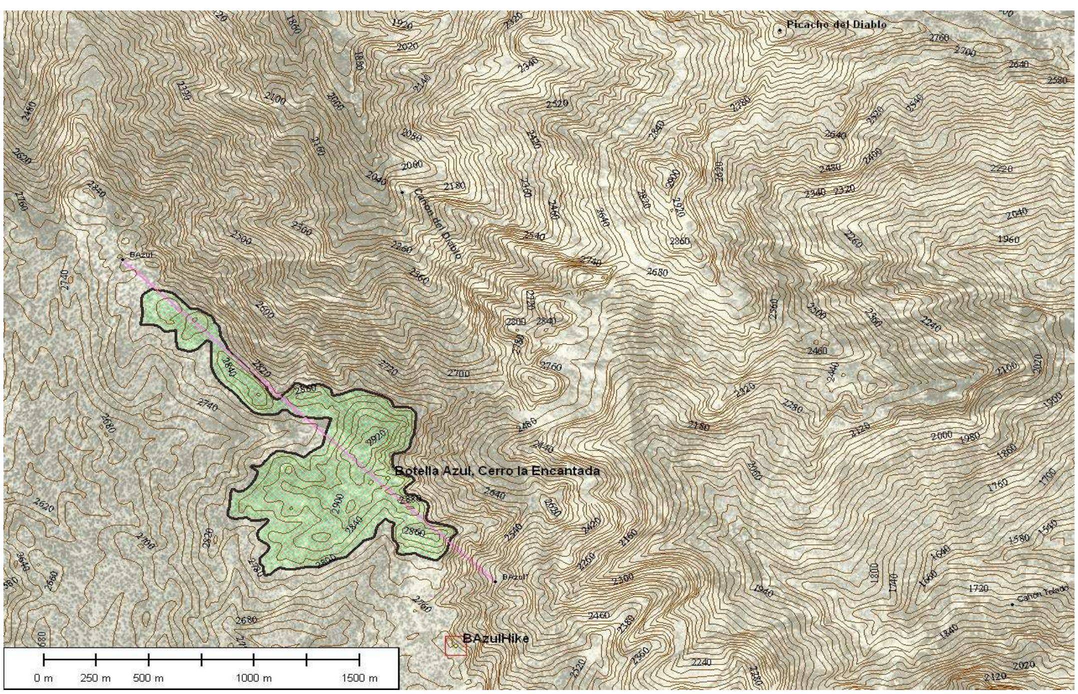

Fig. 14. Topographic map (orthophotographs with elevation lines) of Botella Azul or Cerro la Encantada site. This site presents a roughly 2.5 km long ridge with altitudes in excess of 2800 m. Approach is difficult and the area would have to be leveled several meters to be useful.

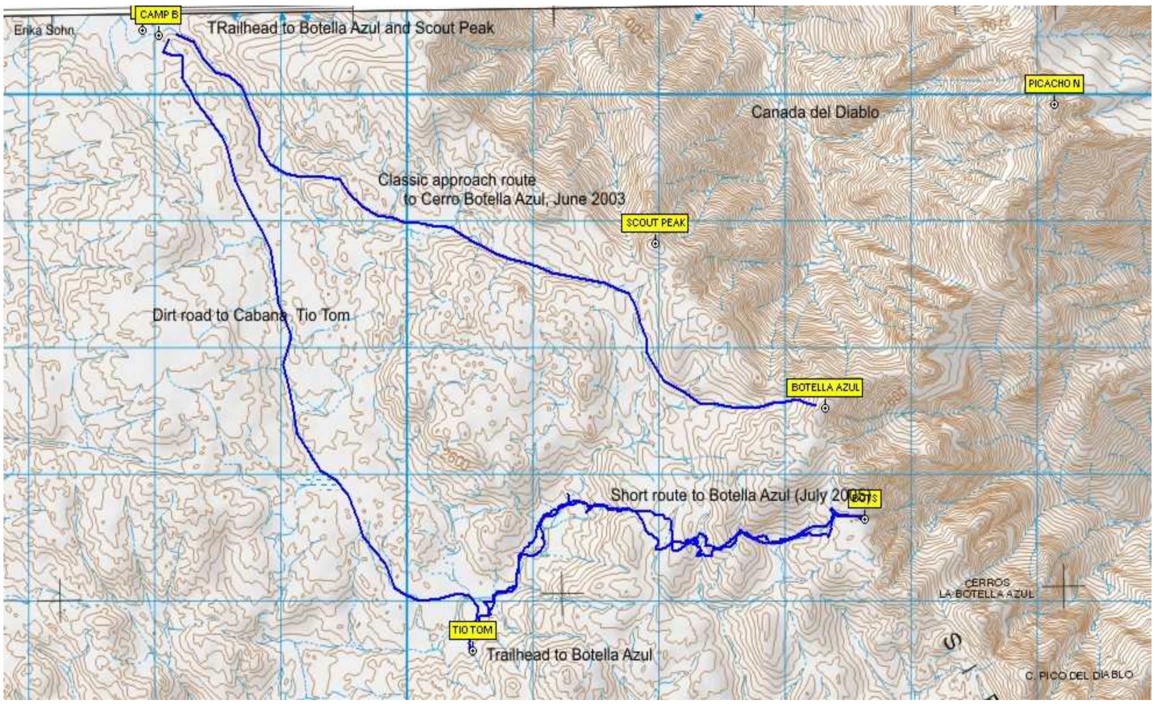

Fig. 15. Approach routes to Cerro Botella Azul. The northern route is the classic Picacho del Diablo climbing route. The southern route follows a 4WD road to Cabaña del Tío Tom; from there the approach is a routeless cross country hike. Each square represents 1 km. North is up.

above 2820 m is about 72.5 ha. Figure 11b shows a roughly 2.5 km long section across this ridge (BAzul-Bazul*). Table 9 lists several waypoints taken at this site This site represents the edge of the national park boundary and is outside the assigned area for astronomical use. Its linear distance from the 2-m site is about 10.5 km and current accessibility is difficult. To reach the trail head, a one-hour drive has to be made from the living quarters. Two possible access routes were devised: the traditional Picacho del Diablo climbing route that starts at the camp site at the end of the allowed 4WD road and one that starts at the Cabaña del Tío Tom. Both take about 3–4 hours, one way, rough hiking (cf. Figure 15). The summit is a rocky, granite, boulder strewn narrow peak. The rocks at this site also present spheroidal weathering. The site would have to be leveled several meters to be useful for construction (cf. Figure 8c).

TABLE 9

BOTELLA AZUL WAYPOINTS

Name	Easting	Northing	Altitude
Botella Azul	11R 653400	3427325	2950 m
BAzul Hike	11R 653722	3426448	2770 m
Cabaña T-T[a]	11R 650614	3425412	2476 m
Scout Peak	11R 652057	3428629	2850 m

[a]T-T: Tío Tom.

3. CONCLUSIONS

Several sites, suitable for the installation of large telescopes, exist in the Sierra de San Pedro Mártir, BC, Mexico. Some of these sites are readily accessible or close to OAN infrastructure as well as to roads, whilst others require minimum road work in order to be reached and to install seeing measuring devices. Two potential sites were visited which are hard to get to, even on foot. Some possible access routes were devised but require major road work in order to be reached for formal site testing. Some sites are outside the OAN boundaries and some even outside SPM Park boundaries. There are some locations that are uniquely beautiful and should be better left pristine. There are two preferred sites: Altar, and Cerro de las Antenas, due to their proximity to existing infrastructure, accessibility and apparently similar conditions to the 2-m site. Additional potential sites were identified along the northern SPM escarpment towards the Venado Blanco location which should be explored in more detail.

The author would like to thank Joaquín Bohigas for motivating this project and for the useful information offered for this work. The support offered by the staff of the Observatorio Astronómico Nacional at SPM during this work was greatly appreciated. The help of Juana Orta and Verónica Alemán in translating the text into Latex was also valued. This work provided the author with the best excuse to seriously explore this wonderful place without the inherent guilt of hiking in SPM.

REFERENCES

Carta topográfica H11B45 San Rafael, INEGI, 5ta. impresión, 1999

Carta topográfica H11B55 Santa Cruz, INEGI, 3ra. impresión, 1988

Carta geológica H11B45 San Rafael, CETENAL, 1ra. edición, 1976

Carta geológica H11B55 Santa Cruz, CETENAL, 1ra. edición, 1977

Comisión Federal de Electricidad, 2001, Estudio geotectónico para la cimentación del Telescopio Optico Infrarrojo Mexicano (TIM) SPM, Baja California (01-21-SGM/R)

Cruz-González, I., Avila, R., Tapia, M. (ed.) 2003, San Pedro Mártir: Astronomical Site Evaluation, RevMexAA (SC), 19

Gastil, R. G. 1993, Geol. Soc. America, Special Paper 279, 145 [IA1]

Martín-Barajas, A., & Delgado-Argote, L. 1995, Inventario de Recursos Minerales del Estado de Baja California, (Cap. 2, p. 20-77) Departamento de Geología, CICESE, Secretaría de Desarrollo Económico del Gobierno del Estado de Baja California

Ortega-Rivera, A., et al. 1997, Geol. Soc. America Bulletin, 109, 728

Phillips, S. J., & Wentworth, P. 2001, Comus eds., A natural history of the Sonoran desert, Arizona-Sonora Desert Museum, Arizona, The University of California Press

Walawender, M. J., Gastil, R. G., Clinkenbeard, J. P., McCormick, W. V., Eastman, B. G., Wernicke, M. S., Wardlaw, M. S., & Gunn, B. M. 1990, Geol. Soc. America Memoir, 174, 1