

## THE KINGDOM OF MOROCCO

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The Roman province of Mauritania was invaded by Muslims in the 7<sup>th</sup> century AD, leading to the founding of the present country of Morocco as an independent kingdom in the 9<sup>th</sup> century. Later centuries saw occupation by the Portuguese, English, Spanish and French. In 1912, two protectorates were established: French Morocco, on the Atlantic coast which included most of the present country and Spanish Morocco on the Mediterranean coast. In recent years, the kingdom has annexed much of the former Spanish Sahara. The geodetic history of the entire country is a combination of Spanish and French influences. The coordinate systems of Morocco are among the more difficult to comprehend and unusual in the entire world.

The first-order Frontier Triangulation of Spanish Morocco was attached to Spain by measurements of the Instituto Geográfico y Catastral de Madrid in 1923-1929. It was composed entirely of one meridional arc and was originally referenced to the Madrid Datum on the Struve ellipsoid. This was locally computed on the Beni Meyimel Gauss-Krüger Transverse Mercator Grid of 1923 that was adjusted in the late 1950's to the European Datum of 1950. Station Beni Meyimel on ED50 is:  $\phi_o = 35^\circ 45' 34.223''$  North,  $\lambda_o = 5^\circ 41' 09.5168''$  West of Greenwich. The local Spanish Grid origin for Puerto de Tánger (Port of Tangier) was at Faro (Lighthouse) de Malabata where:  $\phi_o = 35^\circ 48' 47.7''$  North,  $\lambda_o = 5^\circ 44' 57.0''$  West of Greenwich. Neither of these Grids had false origins. The same triangulation arc was later completely recomputed with respect to the namesake of the capital of the former Spanish Morocco, the Tétouan Datum of 1929 where:  $\Phi_o = 35^\circ 35' 41.493''$  North,  $\Lambda_o = 5^\circ 19' 19.545''$  West of Greenwich. The azimuth to Tétouan South West Base is:  $\alpha_o = 231^\circ 44' 50.67''$ .

There were two types of classical triangulation in French Morocco. The original triangulation, the "Reconnaissance Triangulation," was started about 1910 and covered a major portion of the country. It was accom-

plished by Topographic Engineers attached to French Foreign Legion troops engaged in the conquest of Morocco. The work was done on a yearly basis to satisfy military needs, and the officers in charge did their own computations. Errors were cumulative because values for the last 2 or 3 primary stations were accepted by the extending party the following season. The work was accomplished in approximately 40 different portions, and was not as well coordinated as the previous 50 years worth of French efforts in adjacent Algeria. The Reconnaissance Triangulation is referenced to the Agadir Datum of 1921 where:  $\Phi_o = 30^\circ 25' 25.0''$  North,  $\Lambda_o = 9^\circ 37' 48.06''$  West of Greenwich. The origin is the minaret of a mosque in the 16<sup>th</sup> century Port of Agadir. The solar azimuth to Signaux de Founti is:  $\alpha_o = 109^\circ 19' 36''$ . A subsequent Polaris observation (2 pointings) was not adopted.

The French North African ellipsoidal Bonne projection was used for the Reconnaissance Triangulation, and this Grid continues to influence mapping systems in North Africa to this day. Proper computation of these Grid coordinates must be performed from the series form of the equations for millimeter accuracy. Texts that suggest the universal use of spherical formulae with the equivalent authalic radius and latitudes are wrong! The Latitude of Origin ( $\phi_o$ ) =  $35^\circ 06'$  North, and the Central Meridian ( $\lambda_o$ ) of zero degrees from Paris corresponds to  $2^\circ 20' 13.95''$  West of Greenwich. The False Origin is 100 kilometers for both Eastings and Northings. This Grid has perplexed novice cartographers (and many "old pros") for decades. Even more confusing, some implementations of this Grid display no False Origin. The active use of this Grid was terminated in 1942, but it continues to confound, as I shall explain later.

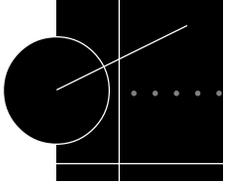
The second type of French triangulation commenced in 1922, and is known as the Triangulation Régulière (regular triangulation). This work was carried out entirely by Topographic Brigades of the Service Géographique de l'Armée (Army Geographic Service), sent from Paris to Morocco. All computations were performed in Paris. The Régulière Datum of 1922 is based on the origin at the astronomic station Merchich 1921 (south of Casablanca),

where:  $\Phi_o = 33^\circ 26' 59.672''$  North,  $\Lambda_o = 7^\circ 33' 27.295''$  West of Greenwich. The azimuth to station Mohammed El Kebir is:  $\alpha_o = 46^\circ 52' 11.291''$  (from south), and the ellipsoid of reference is the Clarke 1880 where:  $a = 6,378,249.145$  meters, and  $1/f = 293.465$ . During the same era, of 7 baselines that were measured for the classical triangulation, Ber Rechid and Agourai were locally adopted as temporary datum origins. The Ber Rechid 1920 Datum is defined where:  $\Phi_o = 33^\circ 17' 41.6''$  North,  $\Lambda_o = 9^\circ 56' 02.05''$  West of Paris. The azimuth from North Base to South Base is:  $\alpha_o = 169^\circ 34' 15.3''$ . The geodetic definition of the Agourai Datum seems to be lost, but it may exist somewhere in Rabat or Paris. The remaining baselines of the Régulière Datum of 1922 included Marrakech, Guercif, Taroudant, Bon Denib, and Sidi Ben Zekri, where "sidi" is an Arabic term of obeisance, similar to "my lord." In the 1950's, the U.S. Army Map Service (AMS) found the Régulière classical triangulation to be intrinsically correct.

The Lambert (partially conformal) Conic projection is used for the Régulière Datum of 1922, and this Grid also confounds cartographers to this day. There are two original zones: for Zone Nord, the Latitude of Origin ( $\phi_o$ ) =  $33^\circ 18'$  North (or  $37^g$  where  $100$  grads =  $90^\circ$ ), the Central Meridian ( $\lambda_o$ ) =  $5^\circ 24' (6^g)$  West of Greenwich, and the Scale Factor at Origin ( $m_o$ ) =  $0.999625769$ . For Zone Sud, the Latitude of Origin ( $N_o$ ) =  $29^\circ 42'$  North, the Central Meridian ( $\lambda_o$ ) =  $5^\circ 24'$  West of Greenwich, and the Scale Factor at Origin ( $m_o$ ) =  $0.999615596$ . The False Origin is 500 kilometers for Eastings and 300 kilometers for Northings for both zones. The formulae used with this Grid have a long and lurid history dating back to the 19<sup>th</sup> century, courtesy of the French way of doing things.

During the 19<sup>th</sup> century, France was the center of cartographic research in the mathematics of map projections. Because projection table computations were performed by hand, all formulae were commonly truncated past the cubic term to ignore infinite series terms considered at the time, too small to warrant the extra effort. For instance, the Lambert Conformal Conic projection was used only to the cubic term in the formulae for the tables of the

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developed meridional distances. This resulted in French Army projection tables that have become part of the arcane lore of computational cartography. This "secret" has been explicitly detailed in the French literature for a century, but apparently ignored by readers of English-only papers. Standard Lambert formulae will not work for Morocco, and the use of fully conformal formulae will yield computational errors that exceed 15 meters! Note that mathematical elegance is not what matters in a country's coordinate transformations; what matters is computational conformity to local legal standards. In Morocco, one had better use the French Army Truncated Cubic Lambert Conic projection. Watch out for that "shrink-wrap" software in perfect conformity with United States Standards.

The Maroc Nord and Maroc Sud zones have an eastern limit to their Grids that are defined by the 448,000 meter Easting (X) coordinate of the North African ellipsoidal Bonne projection. The intersection of this Grid limit with the graticule was a graphical simplicity but a computational nightmare until the paper of Karl Rinner was used at AMS. In the 1930's, Professor Rinner published a paper (in German) detailing his development of the formulae for the ellipsoidal Bonne projection in series form. AMS developed a reversion of his series, and computational algorithms were developed for the North African Bonne in Morocco among other places.

In the past 50 years or so, a couple of other places on the Atlantic coast have been rumored to be datums in Morocco. Those places are Modagor and Sidi Ifni. Neither of these are datums; rather, they are local Grids based on the Réguliere Datum of 1922. In particular, the Sud d'Ifni 1955 Hatt Azi-

muthal Equidistant Grid is defined at the origin point (Camp monument at Maison Guizol) where:  $(\phi_o) = 29^{\circ} 02' 06''$  North, the Central Meridian  $(\lambda_o) = 10^{\circ} 30' 06''$  West of Greenwich, and the Scale Factor at Origin  $(m_o) = 1.0$ . The False Origin is 50 kilometers each for Eastings and Northings. The orientation of the Grid is defined to "Fourmi" as:  $\alpha = 40^{\circ} 19' 47''$ . The Mogador 1957 Lambert Grid origin is:  $(\phi_o^s) = 31^{\circ} 30'$  North, the Central Meridian  $(\lambda_o) = 10^{\circ} 00'$  West of Greenwich, and the Scale Factor at Origin  $(m_o) = 0.999932968$ . The False Origin is 200 kilometers each for Eastings and Northings. In 1921, the position of Mogador Mat on the Reconnaissance Triangulation was:  $\phi = 31^{\circ} 30' 36.7''$  North,  $\lambda = 9^{\circ} 46' 31.2''$  West of Greenwich. The same point on the Réguliere Datum of 1922 is:  $\phi = 31^{\circ} 30' 13.178''$  North,  $\lambda = 9^{\circ} 46' 23.643''$  West of Greenwich. The Mosque d'Agadir has also been recomputed on the Réguliere Datum of 1922 as:  $\phi = 30^{\circ} 25' 54.785''$  North,  $\lambda = 9^{\circ} 37' 36.811''$  West of Greenwich.

The Kingdom of Morocco added two more zones to their national Grid system to cover the annexed former Spanish Sahara. Maintaining a single national Central Meridian  $(\lambda_o) = 6^c$  West of Greenwich; for Zone III the Latitude of Origin  $(\phi_o) = 29^c$  North, the Scale Factor at Origin  $(m_o) = 0.999616304$ , and the False Origin is 1,200 kilometers Easting, 400 kilometers Northing. For Zone IV the Latitude of Origin  $(\phi_o) = 25^c$  North, the Scale Factor at Origin  $(m_o) = 0.999616437$ , and the False Origin is 1,500 kilometers Easting, 400 kilometers Northing. The National Imagery and Mapping Agency (NIMA) lists the shift from "MERCHICH Datum" (sic) to WGS 84 Datum as:  $\Delta X = +31$  meters  $\pm 5$  m,  $\Delta Y = +146$  meters  $\pm 3$  m,  $\Delta Z = +47$  meters  $\pm 3$  m. This relation is based on nine stations somewhere in Morocco.

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