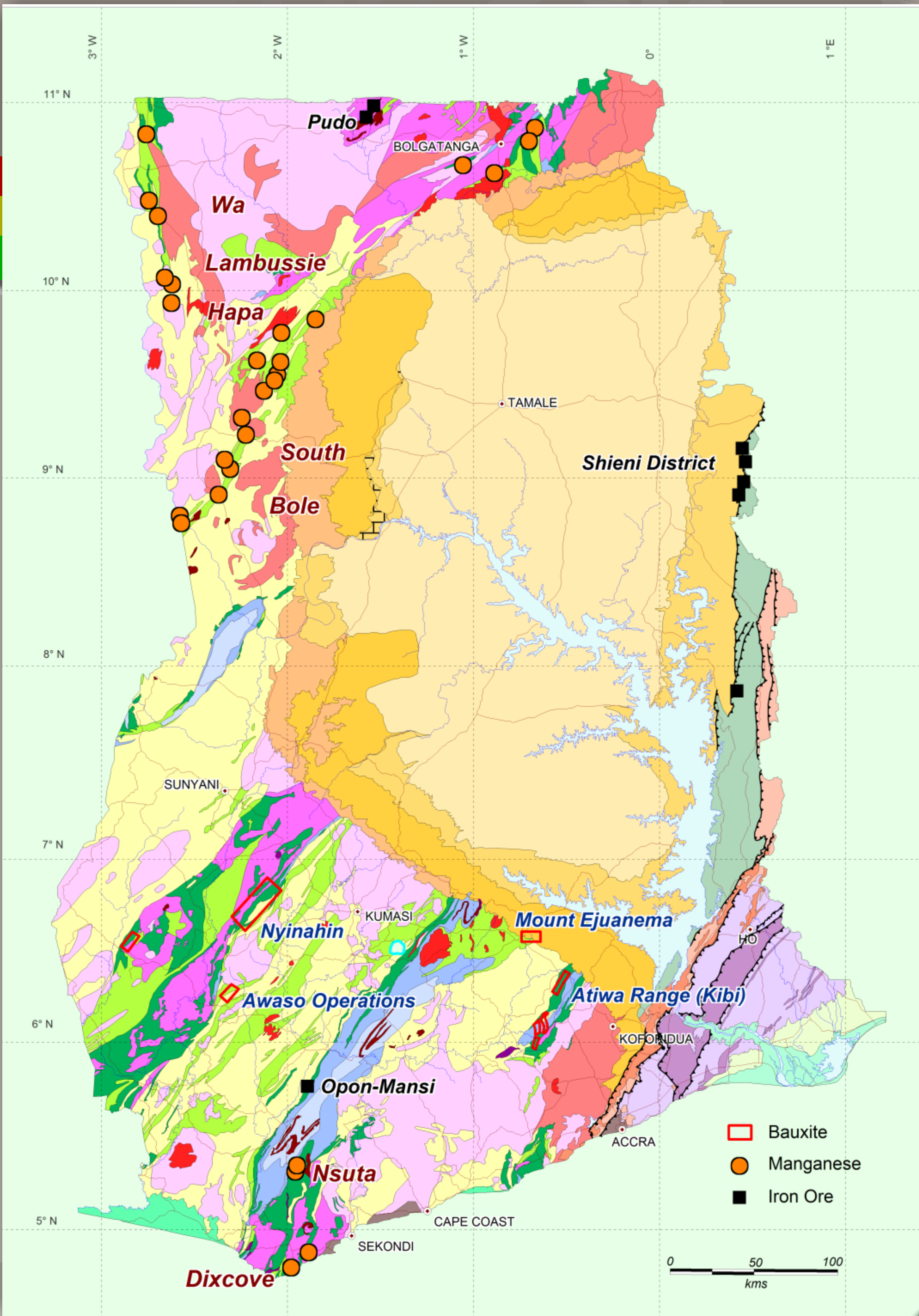
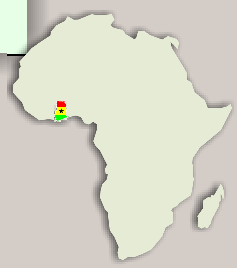
Manganese, Bauxite and Iron Ore Occurrences in Ghana





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Manganese in Ghana

INTRODUCTION

Ghana has been a significant manganese (Mn) producer for almost a century after the initial discovery of the huge, high-grade Nsuta deposits in May 1914, just as war was about to engulf much of Europe. The discovery was made by the venerable Sir Albert E. Kitson, the first Director of the Geological Survey, while he was carrying out a traverse from Kumasi to Sekondi, along the new railway line. Due to the war-time need for steel, open-pit mining operations were under way by late 1916 and, despite many ups and downs over the decades, Nsuta has been a prolific producer ever since.

The overwhelming demand for manganese is in the iron and steel industry where it remains an invaluable alloy that strengthens steel and makes it more resistant to wear. From a total world production of some 45million metric tonnes (in 2008) of manganese ore, about 90% of manganese is used by iron and steel makers, as well as ferroalloy producers. As would be expected, manganese production reflects general economic conditions in the global economy, especially in relation to building infrastructure and manufacturing. Not surprisingly, in recent years the rapidly growing economies of Asia, especially of China and India, have been the major users of manganese and commodity prices have been quite robust.

Of course, manganese has many other uses in a great variety of forms. Common manganese dioxide has been traditionally used in large amounts for dry cell batteries as an electron acceptor and it continues to be used in alkaline batteries but it does not have a major role in the fast growing lithium battery industry. In glass manufacturing, it has been used for centuries as a pigment for colouring and in neutralizing the effects of minor amounts of iron in the glass flux. It is also now used quite extensively as an alloying agent in the manufacturing of aluminium where a very small amount of Mn significantly increases the resistance to corrosion.

Complex manganese compounds also play an important if not vital role in many other areas such as in medicine (for example, permanganates) and in fertilizers where it is an essential nutrient for plants and animals. It is also used in the form of complex organo-metallic compounds, which can be added to petrol to improve combustion.

The major manganese ore producers are South Africa, Brazil, Gabon, China, Australia, Ukraine, India and Mexico. South Africa has the largest established continental reserves in the world by far, mostly in the Kalahari Desert. Ghana, which produces just over 1 million tonnes of Mn-concentrate per year, remains a significant producer on the world scene. Ghana's neighbours, Burkina Faso and Cote D'Ivoire have significant high-grade manganese deposits that have seen limited production. It is also known that very large resources of manganese nodules occur at numerous locations on present-day sea-floors, mainly in the Pacific Ocean. These nodules also contain significant amounts of other metals, including copper, nickel and cobalt; as yet the means to mine these resources on an economic basis have yet to be established but they are a resource of future value.

The following will summarize key aspects of the geology and potential for the development of new manganese operations in Ghana with an emphasis on prospective areas with known deposits. Much of this information comes from Ghana Geological Survey Bulletin 44 by G.O. Kesse (1976).

GEOLOGICAL SETTING AND CHARACTERISTICS OF MANGANESE DEPOSITS

In Ghana and for much of West Africa, manganese is a very widespread metal, most commonly found in Early Proterozoic (Birimian - approx. 2100-2200 Ma) sediments that occur throughout the West African Shield. In fact, the widespread occurrence of manganese in the Birimian units is one of the key distinguishing features of the Birimian throughout West Africa. Whereas older Archean greenstone belts throughout the world host major banded iron ore deposits, Birimian units typically contain much more banded manganese deposits than iron.

In the very broadest terms, most of Ghana is underlain by narrow, Birimian 'greenstone' belts flanked by broad sedimentary basins, many of which also feature huge granitoid intrusions derived from the sediments. Regional models now visualize the belts and the basins to have formed more or less contemporaneously with the basins being derived from the erosion of the nearby volcanic chains. Along the margins of the belts and basins are volcaniclastic and clastic units interbedded with chemical sediments, which may include very fine-grained siliceous (cherty) units, iron sulphides (usually pyrite), carbonates, graphitic units and banded manganese. This same suite of chemical sediments can also be found well within the greenstone belt terrane where most of the major manganese deposits are located.

The banded manganese units may be restricted to relatively narrow stratigraphic sequences a few 10s of meters thick traceable along strike for 100s of meters or they may be hundreds of meters thick and traceable along strike for many kilometers. Most often the manganese is observed in the field as blackish banded sediments consisting of a mixture of mainly secondary manganese oxides that may include pyrolusite (MnO_2), manganite ($Mn_2O_3.H_2O$) and often widespread psilomelane, a complex hydrated manganate with an approx. formula of (Mn, Ba, K_2).MnO_3.xH_2O. In some circumstances, these complex secondary oxides have been re-distributed into dense concentrations of quite high-grade ore, such as observed at Nsuta (see below), and usually found capping hills.

The nature of the original manganese mineralization is often difficult to determine because first, almost all Birimian units have been metamorphosed to greenschist or higher grade metamorphic facies, and secondly, the effects of weathering over the past few million years have altered the metamorphic mineralogy considerably. Therefore, underlying many of the high-grade concentrations of complex secondary oxides are manganese-rich units with fine-grained spessartite, a Mn-rich garnet of metamorphic origin that is often associated with quartz-rich units, which are collectively referred to as "gondite", a common term in the geological literature of Ghana.

In some cases, for example at Nsuta, the secondary oxides are underlain by beds of manganese carbonate (rhodochrosite – MnO_3) that are believed to be the primary manganese mineralization at this locality. It would also seem reasonable to expect that much of the primary mineralization in some areas could well have been a variety of oxides and that you will get different sedimentary facies (oxide and carbonate) representing environments in which the chemical sediments were deposited, similar to the sedimentary facies seen in many Archean banded iron formations.

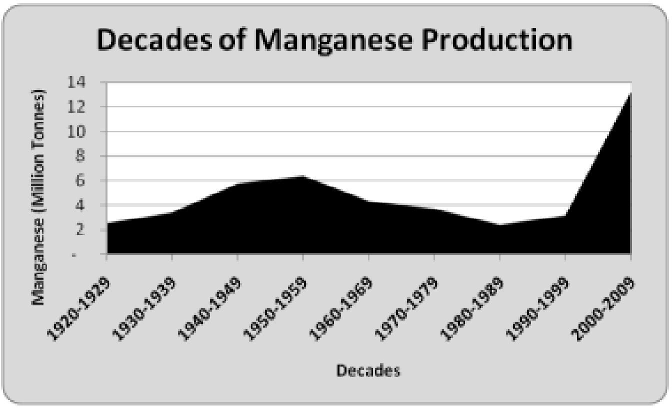
Since the Early Tertiary, much of Ghana has been exposed to extensive weathering as demonstrated by widespread laterites and deep weathering profiles throughout the region. In places, the end products of the weathering process are high concentrations of iron and aluminum oxides, such as iron formation and bauxite, and where there are underlying banded manganese, the overlying lateritic crust is very rich in manganese oxides. Such is the case in many parts of Ghana where weathering has converted lower grade manganese silicates, carbonate or oxides to high grade secondary oxides and manganates.

In most of the gold districts in Ghana, there seems to be a general association between manganese and gold mineralization, although perhaps it is best to describe the association to be between gold and chemical sediments in general, of which manganese is often a prominent member. There are a few cases where significant gold mineralization, usually in quartz veins or stockworks, is actually hosted in manganese-rich sediments but these are not so common. Nevertheless, this association may be quite important and it has been suggested that the chemical sediments, which in places are quite anomalous in gold, may be a significant primary source of Birimian gold and that during the Eburnean orogeny, hydrothermal fluids driven through the complex structures along the margins of the greenstone belts where a lot of the chemical sediments are located, have flushed gold from the sediments and concentrated them in more favourable structural settings.

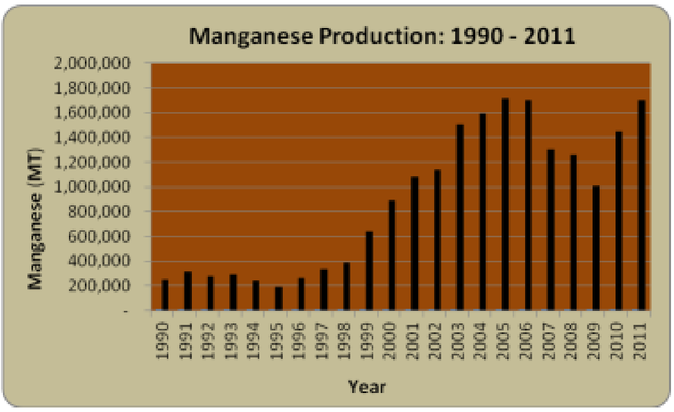
NSUTA MINE

Kitson's initial discovery of the high-grade Mn deposits at Nsuta were quickly followed up and by late 1916, production was underway as manganese was critical for the production of steel needed in the ongoing war effort in Europe. By the mid 1920s, open-pit production had been increased to over 1000 tons per day (approx 360,000 tons per year) and the operation, then operating under the name of African Manganese Company, a wholly-owned subsidiary of Union Carbide of the USA, was the largest manganese mine in the world and employed over 1500 workers. The roaring 20s was a period of growth in many countries, especially the USA, which needed a lot of steel and the Nsuta operations responded by increasing annual production to about 500,000 tons at the end of the decade.

The Great Depression of the 1930s resulted in a dramatic drop in production to less than 100,000 tons in 1932-33 but it built back up over the latter half of the decade. During World War II, steel was again in great demand and the operation sustained production levels close to 500,000 tons per year and included about 3000 employees. High production levels were maintained immediately after the war and throughout the 1950s when production peaked at about 700,000 tons in 1956-57. In the 1960s and until 1972, annual production leveled off to around 450-500,000 tons and overall employment had dropped to about 1300 personnel. In 1973, the operation was taken over by the Government of the day and thereafter, production levels dropped off to about 300-400,000 tons per year for the remainder of the decade.



1980s were very difficult years for the Ghana National Manganese Corporation (GNMC) and annual manganese exports dropped below 200,000 tons but increased to about 300,000 tons towards the end of the decade and throughout much of the 1990s. Late in 1995, GNMC was privatized and is now called the Ghana Manganese Company Limited or GMC. Major investments in exploration, new treatment facilities and efforts to improve the railway transport system resulted in production increases from about 400,000 tons in 1998 to over 1 million tons at the beginning of the new millennium.
Over the past 10 years, production records were consistently achieved early in the decade, with a peak of just over 1.7 million tonnes by 2005. Since then, exports have dropped significantly to just over 1 million tonnes the past few years. The drop in production has been mainly due to bottlenecks in the transportation network, especially the deterioration of the railway line from Nsuta to the Port of Takoradi, which necessitated much more overland trucking. Except for the sharp drop in demand for steel in 2008-09, most of the decade saw very high commodity prices, which did offset much of the drop in production late in the decade.



The Nsuta mine will soon reach its centennial year of operation, which is quite a milestone for any mine. It has now exported about 50 million tonnes of concentrates and the mine will likely remain a major producer for several more decades. Most of the production was from high-grade oxide ores, which sustained the operation for many decades. Eventually the deeper open-pit mining started to exploit the underlying primary carbonate ores, which are now the focus of the operations. These carbonate ores are not as high-grade as the overlying oxides but they are valuable as a blend for other ores. The run of mine carbonate ores are merely dry crushed and screened prior to shipment to overseas customers.

OTHER IMPORTANT OCCURRENCES

As noted above, manganese occurrences are common throughout the Birimian units of Ghana and West Africa in general. It therefore seems a little surprising that more commercial quantities of manganese have not been developed in other parts of Ghana. The problem, like most bulk commodities of relatively low value and limited market, is that easy access to foreign markets is critical, which means transport costs have to be very low. Thus, Nsuta very much benefitted from its proximity to a railway line a short distance from a major port where ships could carry the oxide ores to the markets where steel was being manufactured in the USA, Europe or Asia.
The following will look at selected areas in southern and northern Ghana where there are known manganese occurrences of substantial size and/or grade to be candidates for possible development in the future

DIXCOVE AREA - SOUTHEAST ASHANTI BELT

Just to the north (approx. 4-5km) of the coastal fishing village of Dixcove, there is a series of quite prominent hills trending approx. NE for a distance of about 10km from west of Azani to Hautopo on the east and extending almost to Bokro on the main Takoradi-Agona highway. The hills have relief in the range 50-100m; they are mostly steep-sided and are capped by flat-topped laterites that represent old (mainly Tertiary) weathered surfaces (peneplains). Most of these hills are underlain by significant manganese deposits, some of which were mined during World War II and for a few years after.

Rather interestingly, the deposits appear to be part of a narrow (approx. 1-2km) band of Birimian metasediments and volcaniclastics, almost entirely surrounded by Birimian intermediate granitoids of the belt type, also often referred to as the Dixcove-type intrusion. This band appears to cut more or less across the main NNE trending belt of intrusions and volcanics and the regional faults that are widespread in the area. The manganese deposits are mostly along the east side of the band of metasediments and they occur in a variety of forms. As at Nsuta, the higher grade manganese in this district occurs mainly as secondary concentrations of oxides and manganates, the result of extended and complex weathering processes. These include resistant lateritic iron-manganese cappings and detrital concentrations that are from 2 to about 6m thick; grades are mostly in the range 10-20% Mn but some are as high as 30%. The main deposits usually are very low in phosphorous (less than 0.5% P_2O_5) but high in silica (10-25% SiO_2) and iron (5-20% Fe). Unlike Nsuta, there do not appear to be significant concentrations of massive manganese oxides nor carbonates beneath the cappings, which grade into manganiferous phyllites and gondite (quartz and Mn-garnet).

The deposits include those at the western end of the band (Yakau, Himakrom, Aketechi) on the west side of the Butre River and the Hautopo deposit on the immediate east side of the river. Over the years, especially in World War II, some mining took place at several of the deposits where high-grade metallurgical ore was hand-picked and then trucked to the nearby Port of Takoradi and sent abroad. However, the tonnages mined appear quite modest at Yakau-Himakrom (approx. 22,000 tons). In the 1960s, the Soviets carried out an evaluation of the tonnage potential of the Yakau-Himakrom and Aketechi deposits; their estimates indicate a collective resource of 4.4 million tons grading about 10%Mn.

The Hautopo deposit on the east side of the Butre River was under control of Union Carbide for many decades and is now held by Ghana Manganese Corporation Limited. At this location apparently the deposits are very similar but somewhat better grade than those described above. During World War II to about 1954, this area was worked intermittently; there are no details available on production but it would seem to have been modest.

The proximity of these deposits to the Port of Takoradi will enhance opportunities for their development in the future.

AXIM-SALMAN AREA – SOUTHWEST ASHANTI BELT

Just to the north of the coastal city of Axim is another narrow belt of Mn-rich metasediments that extend northwards for about 10km to the Salman area, just to the west of the Ankobra River. These occurrences were first reported by members of the Geological Survey in the early 1930s as they were mapping and examining areas close to the old road from Axim to Tarkwa, which was a vital access track in the early years of modern gold mining in the Tarkwa District, prior to the building of the railway from Sekondi. The area was later evaluated in the 1940s and 1950s for the manganese potential.

The principal manganese occurrences appear to be mainly restricted to the tops of a series of low hills close to the village of Salman where they occur as lateritic cappings overlying manganiferous and carbonaceous Birimian phyllites. The area also features extensive faulting and quartz veining is widespread in some areas. In fact, the area hosts significant gold mineralization and recently (2010) a gold mine has been developed at Salman by Adamus Resources of Perth, Western Australia.

The lateritic cappings are only 1-2m thick but cover substantial areas; to date, very little significant underlying manganese has been detected in any of the hills but along the sides of the hills there are substantial accumulations of large Mn-rich boulders that are quite high grade (40+% Mn). This area was once held by Ghana National Manganese Corp but it was not included in the assets privatized under Ghana Manganese. The overall size potential of the occurrences in this area is not very great, possibly 1-2 million tonnes with grades above 20% Mn but they are now quite accessible in an area not very distant to the Port of Takoradi and could possibly be developed on a relatively small scale.

SOUTH BOLE DISTRICT (Northern Region)

The NE trending Bole-Nangodi greenstone belt is riddled with manganese occurrences, especially the southern 100+km section from the Black Volta northwards to the Lovi River. This 'typical' Birimian belt features a great variety of interbedded volcanics, volcaniclastics and chemical sediments that in places have been intensely metamorphosed (amphibolite facies) and deformed. Amongst the chemical sediments are extensive units rich in manganese, often associated with graphitic material.

Much of this area was first mapped and prospected in the 1920s by various members of the Geological Survey who carried out traverses across most of the region and spotted many of the better known manganese prospects, which mainly occur in small hills that stand above the flat surrounding countryside. This early work was followed up in the early to mid 1960s when Soviet prospecting and mapping teams were involved in evaluating large areas of northern Ghana, including many of the known manganese deposits, especially those in the area south of Bole. The Soviet work included pitting, trenching and drilling to shallow depths on several of the major occurrences.

Almost all of the manganese occurrences have many features in common. They occur as lenses within thick sequences of highly folded phyllites; the individual beds of manganese vary in thickness from less than 1m to more than 5m but may be considerably thicker where they occur in the hinges of folds. Individual lenses may vary from a few 10s of meters to 100s of meters long. The higher grade sections occur mainly in the upper oxidized (supergene) portions and feature a variety of secondary oxide minerals. The underlying primary material usually includes abundant Mn garnets with variable amounts of manganese oxides, iron oxides and quartz; in places, manganese carbonates (rhodocrosite) are also abundant. The depth of the supergene enrichment apparently does not go beyond the depth of the water table, which typically would be no more than 25m but may be a little more on some higher hills. The most promising manganese deposits in this area are about 5-7km east of the small border village of Ntereso and 27-28km south of Bole, a district capital within the Northern Region. These deposits are along the east side of the Sheri River valley, a small tributary to the nearby Black Volta. The two most significant occurrences are at Kapili Hill, which is reported to be an abrupt hill with relief of 40-50m and is the more easterly occurrence, and Three Hills, which was discovered by the Soviets and it consists of three closely spaced, low-lying hills with a maximum relief of about 30m. The latter deposit is about 2-3km NW of the Kaplili Hill occurrence. Geological Survey Bulletin 44 (1976) estimates the high-grade (approx. 30% Mn) resource at Kapili Hill to be about 3 million tonnes whereas the lower grade (11-25% Mn) resource is another million tonnes. At the Three Hills prospect, the Soviets estimated up to 2.7 million tonnes of resource averaging about 30% Mn to a depth of 25-30m.

The Kalimbi Hill prospect, which was the first to be discovered in this region in 1924, occurs in a prominent (75m relief) hill almost exactly 13km NE of Three Hills and along the same manganiferus band on the east side of the Sheri River valley. Here, the high-grade resources are apparently quite limited but the Soviets did outline significant lower grade (14 % Mn) resources of about 6.5 million tonnes to a depth of 25-30m.

None of the deposits evaluated by the Soviets in the early to mid 1960s were considered to be economic because of the limited high-grade material and the high transportation costs from this relatively remote location. However, in the current markets, the economics may be substantially improved. This would be favourably affected by the availability of hydro-electric power from the nearby Bui dam that is currently under construction, which would allow the manganese to be upgraded at site. Also, if plans to greatly expand and improve the barging facilities on Lake Volta are carried out, the transportation costs to the Port of Tema could be substantially reduced.

WA-LAMBUSIE-HAPA (Upper West Region)

The Wa-Lawra greenstone belt also features many known manganese occurrences, all with similarities to those described above. Again, much of this area was evaluated in the 1960s by Soviet prospecting teams that carried out extensive sampling and limited drilling in the area.

There is an approx. 15km long band of Birimian metasediments extending from around Lambusie right to Hapa on the Burkina Faso border; this broad band (100-200+m wide?) strikes almost north-south and hosts numerous manganese occurrences that are exposed in many of the low hills of the area. The manganese occurrences are quite typical for the region; most occur as thin beds or lenses from less than 1m up to a maximum of about 10m thick and extending along strike for 10s on meters to 100s of meters. The metasediments are mainly seen as mica schists, often with significant fine-grained graphite. The manganese units feature mixtures of manganese garnets and various manganese oxides and usually including abundant quartz grains and iron oxides. Reported grades rarely exceed 20% Mn and although the collective tonnage in the area is huge, none of the individual deposits appeared to be very large and the Soviets did not consider the economics to be favourable at the time.

Much further to the south and just to the west of the regional capital of Wa, several manganese occurrences were also reported from the Soviet work in the 1960s. The metasediments in this area have been highly metamorphosed and the manganese is largely seen as gondite (bands of Mn-garnet and quartz) but in some areas, quite extensive beds of fine-grained graphite are observed. In fact, in the course of exploring for manganese at Kambale, almost within the current outskirts of Wa, the Soviets discovered quite a large concentration of fine-grained, flaky graphite. Although rather high-grade and quite large, the flake is too fine-grained to command a premium price. Future exploration in this area may yet discover better occurrences of manganese and/or graphite in this area and it is even possible that a combination of the two could be present in some deposits.

These northern occurrences are hindered by their relatively remote location but, as in the South Bole district, a local source of power (Bui Dam) and improved barging facilities on Lake Volta would have a very beneficial effect on the economics of an operation in this area.

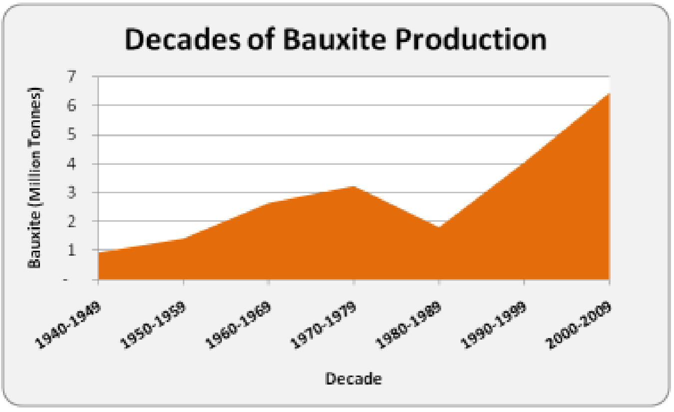
Bauxite in Ghana

INTRODUCTION

The presence of bauxite in southern Ghana was recognized in the earliest days (1913-14) of the Geological Survey when the first Director, Alfred E. Kitson, carried out reconnaissance traverses all across the region and noted boulders of bauxite on the lower slopes of the Atewa Range and along the base of the Kwahu Escarpment. Subsequent work by the Geological Survey over a period of several decades identified numerous bauxite occurencies capping many of the highest hills in southern Ghana.

At the beginning of World War II, Great Britain was in dire need of secure sources of bauxite to produce aluminium for the war efforts. This led to the rapid development of the deposits in the Sefwi Bekwai area (Awaso) of SW Ghana. The selection of Awaso for development had much to do with its favourable and convenient location. By 1943, the Awaso open-pit operations were fully geared up and shipping more than 100,000 tonnes of ore per year by rail to the port of Takoradi and the operation continues to this day.

Bauxite, which is an earthy mixture of mainly hydrous aluminium oxides, is virtually the sole ore for the production of aluminium, one of the most important metals to modern society. This is due to its lightweight, good strength, resistance to corrosion, heat and electrical conductivity, alloying capabilities, and relative abundance. It is used for a great variety of purposes in all walks of life. Its main uses are in the building and transportation industries but it is also vital to the manufacturing, electrical, agricultural, medical, and military industries.



Virtually all aluminium refineries are located in areas where electrical power rates are very low, mostly close to major hydro-electric or gas-fired power plants. This is because the refining process for aluminium , as for most metals, is very power intensive and the economics have favoured shipping high-grade bauxite ores or alumina concentrate by sea to coastal locations with cheap electricity, often from hydro-electric sources and increasingly from gas-fired power generation.

Ghana has been mining bauxite and producing aluminium for many decades. When the Akosombo hydro-electric dam (approx. 900 megawatts capacity at the time) on the Volta River was completed in the mid 1960s, it had excess capacity to the country's immediate urban and industrial needs so the Nkrumah government entered into a long-term contract with the Kaiser group of the USA to provide a cheap source of power for an aluminium refinery in Tema. Oddly enough, the Kaiser group imported alumina (Al_2O_3 – an upgraded product derived from bauxite) from Jamaica for the Tema refinery whilst the Awaso bauxite was being shipped from Takoradi all the way to Scotland for refining. This curious situation resulted from the fact that the refinery in Scotland was specifically designed for the complex Awaso ores, which were unsuitable for the Tema refinery. It is hoped that any future developments in bauxite mining in Ghana will certainly include value-added processing to alumina and/or aluminium within the country.

GEOLOGY OF BAUXITE DEPOSITS

As noted above, bauxite is an earthy mixture of Al-rich minerals (usually more than about 30% Al_2O_3) along with variable amounts of iron oxides, silica and minor clays. Virtually all bauxite deposits are formed by weathering processes, mainly in tropical environments, and result from the removal of almost all the soluble elements (especially Na, K, Ca, Mg minerals) and leaving behind mostly weakly soluble Al and Fe oxides (+/- hydrated forms), some clay (mostly kaolin) and silica, along with minor amounts of accessory minerals such as zircon and thorite, which are chemically and physically very resistant to weathering so they become increasingly concentrated in the residual soil/laterite.

There are really two main types of bauxite deposits, both of which form in a similar manner but in very different geological terrane. The less common type is seen mainly in areas underlain by carbonates and where karst topography is widely developed by groundwater dissolving out underground channels and caves. The result is often large sink holes in which the carbonate is removed and leaving behind clays, which, through further weathering and removal of silica, produce bauxite dominated by hydrous Al oxides and lesser amounts of iron oxides. Deposits of this type continue to be important producers in Jamaica, China, and Eastern Europe and they can form in both tropical and temperate climates.

The more common type of bauxite, as observed in the huge deposits of Western Australia, northern Brasil/Guyana and West Africa, are those formed mainly in low latitudes under wet tropical conditions. The general process is that of laterization of which bauxite is one end-member that is frequently derived from sedimentary bedrock containing abundant Al-rich minerals. Another end-member is very iron-rich laterite where the bedrock is usually rich in ferromagnesian minerals such as in volcanic terrane. In a few instances, where manganese is present in the bedrock, the laterite consists mostly of a very high concentration of Mn oxides such as observed at Ghana's famous Nsuta mine.

The process of laterization is most effective in areas of low relief, low elevation, poor drainage and alternating wet and dry seasons that result in fluctuating water tables, which promotes the concentration of the Fe and Al oxides in the zone of aeration. These deposits often represent peneplains, which are old weathered surfaces that are quite flat and formed close to the regional base-level of erosion. In southern Ghana, an old peneplain is indicated by the flat surfaces and thick laterites on the tops of the highest hills in the region. This old surface probably dates back to at least the Middle to Early Tertiary and was once far more extensive and at lower elevations but it was subsequently uplifted and eroded so that only a few remnants are now preserved.

Laterite/bauxite may form as residual deposits, more or less in-situ, or in secondary, sometimes transported accumulations. The colour varies from off-white to yellow, brown or red and all shades in between; many of the Ghana occurrences are an earthy, yellow-brown colour. The more iron-rich varieties of laterite tend to be in various shades of brown and red, whereas the more Al-rich laterites occur in shades of yellow and brown. Because the deposits are products of weathering, they are typically quite light weight, with a specific gravity in the range 1.25-2.0. The internal structure and texture are often extremely variable and may include massive, vesicular, fragmental, vermicular (worm-like pattern), pisolitic or peletal textures.

As one might also expect, the mineralogy of most bauxites can also be extremely variable and is rarely homogeneous. The dominant Al mineral in most of the West Africa bauxite deposits appears to be gibbsite [$Al(OH)_3$] and lesser amounts of the two closely related minerals, boehmite and diaspore, both of which have the same formula [AlO(OH)]. Iron oxides, often in mixtures of hematite [Fe_2O_3], goethite [FeO(OH)] and other hydrated complexes, are invariably present in most bauxite deposits and certainly so in Ghana as will be seen in the geochemistry of several deposits described below. The clay minerals include mainly kaolinite [$Al_2Si_2O_5(OH)_4$] and closely related halloysite, which is amorphous and contains more water than kaolinite; fine-grained silica [SiO2]is also present in quite variable but usually minor amounts.

Many bauxite deposits are immediately underlain by very kaolinite-rich saprolite that is sometimes referred to as lithomarge. Certainly this seems to be the case in most of the main Ghana occurrences. This close association has been interpreted by some to indicate that very possibly much of the bauxite has gone through a kaolinite stage, which, followed by further chemical weathering, eventually breaks down the clay by leaching out silica and leaving behind gibbsite. In some areas, the kaolin residual clay is quite white and suitable for many cosmetic and industrial uses.

AWASO OPERATIONS-GHANA BAUXITE COMPANY (Western Region)

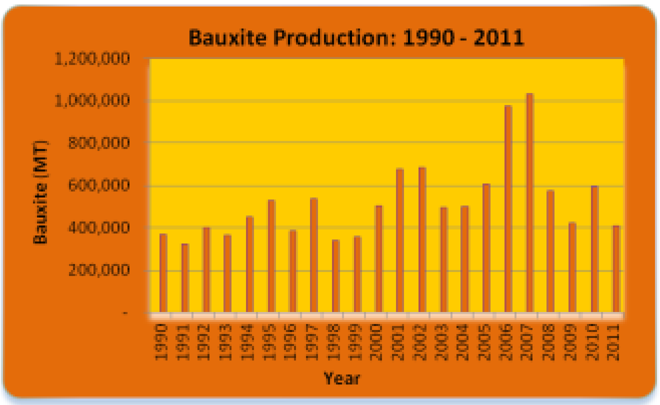
The Awaso deposits, also sometimes referred to as the Sefwi Bekwai Group of occurrences, were first identified by Sir Albert Kitson of the Geological Survey in 1921 and work to assess the area commenced in the following year. The area of immediate attention was in a series of prominent hills just to the north of Awaso where significant bauxite was delineated on the flat tops of several hills.

The steep-sided Awaso Hills, which are in the headwaters of the Ankobra River, have maximum elevations in the range 520-540m ASL, whereas the nearby valleys are mainly below 150m ASL. Much of the bedrock geology consists of NE trending, steeply dipping Birimian metasediments and volcaniclastics; the bauxite deposits, which cap the hills, occur mostly between elevations of 510-530m ASL. The work in the 1920s established considerable size potential (about 30 Mt) on eight of the hills, including six at Awaso and two at a location approx. 16 km NE of Awaso in similar geological and topographic terrain. The grade of the bauxite was reported to be very close to 50% Al_2O_3 and about 3% SiO_2; the iron oxide content of the Awaso bauxites is usually in the range 15-20% Fe_2O_3, which is consistently lower than other deposits in southern Ghana (see below). The average specific gravity (SG) of the bauxite was reported to be about 1.7 (tonnes/m^3 or g/cm^3).

The start-up of World War II led to problems in the supply of aluminium for the Allied forces because, by 1940-41, the Japanese had captured most of the bauxite mines in SE Asia. Aluminium was urgently needed to build aircraft, which were to play an increasingly important role in modern warfare. Great Britain immediately turned to her Africa colonies and the favourable location and considerable size of the Awaso deposits, close to a railway and port, greatly favoured a quick start-up.

The area was acquired by the British Aluminium Company Limited and by mid-1941, hand-picked bauxite was being trucked about 80km to Dunkwa where it was railed to Takoradi for shipment by sea to the aluminium refinery at Burnt Island, Scotland. By 1944, a spur railway line connected Awaso with Dunkwa and a washing plant was established at the mine site. The operation was exporting over 100,000 tonnes per year and employing over 500 local and about 20 foreign staff. The mine has been in operation now for almost 70 years and has produced about 20 Mt of ore.

Over the years, production has waxed and waned pretty much according to world demand. In the 1950s, annual production rose from around 100,000 tonnes to over 200,000 tonnes late in the decade and rose further to over 300,000 tonnes until the mid-1970s by which time the Government had acquired a 55% interest in the operation and the new company was henceforth known as Ghana Bauxite Company Limited. Management of the operation continued to be carried out by British Alcan Chemicals who held a 45% interest in the company.



Significant levels of production were maintained for a few years but there was a sharp drop to less than 200,000 tonnes in 1980 and by the mid-1980s it fell to less than 100,000 tonnes. By the late 1980s, capital investments into new equipment and much improved railway service saw a rapid rise in production that was maintained throughout the next decade. By 1995, over 500,000 tonnes were exported for the first time and high production levels were maintained for the remainder of the decade when the company employed close to 600 local staff and 1-2 foreigners. Another record year was achieved in 2001 when over 700,000 tonnes were exported but this dropped back to around 500,000 tonnes per annum for several years.

Expansion of the operations were again underway by the middle of this decade when annual production jumped from about 600,000 tonnes in 2005 to an average of about 1,000,0000 tonnes in 2006 and 2007. Unfortunately, this was not sustained, in part due to the global financial crisis in 2008, which affected most of the industrialized economies, but especially due to the deteriorating service, including a major strike, by Ghana Railways Corporation. The poor rail service forced the company to ship more and more by road, which increased costs significantly and the results were sharp drops in 2008 to 574,389 tonnes and then a further drop in 2009 to 420,477 tonnes, despite a significant recovery in the world demand, due mainly to continued growth in China, India and other Asian markets. A rise in output in 2010 of 595,092 tonnes could not be maintained in 2011 (409,918).

Recently the Awaso operation was bought out by a Chinese company in the aluminium refinery business and the plans appear to be to accelerate production at Awaso and also establish downstream processing facilities in the immediate vicinity of the port of Takoradi. With plans underway to significantly upgrade the railway routes throughout Ghana, the future operations at Awaso should remain promising for years to come.

NYINAHIN DEPOSITS (Ashanti Region)

Bauxite was first noted in the district in the early 1920s by Dr, W.G.G. Cooper of the Geological Survey on a regional traverse to a very prominent range of hills just to the NW of the town of Nyinahin in the far western part of the Ashanti Region. In fact, this was the southernmost of a series of flat-topped and rounded hills over a length of about 32km, most of which are capped by extensive laterites that include significant bauxite deposits. Over successive decades, numerous studies were carried out in the area to define the regional potential and to evaluate some of the larger deposits, which may be big enough and of sufficient quality to warrant development. Until recently, the vast and generally high quality reserves further to the west in Guinea meant that these and other Ghanaian deposits were of less interest to the major producers but with the increase in demand for aluminium in recent years, especially in the Asian markets, all major bauxite deposits are being re-examined for possible development.

The Nyinahin bauxite occurrences are underlain mainly by Birimian clastic and volcaniclastic sediments, as well as some volcanics, along the eastern margin of the Sefwi volcanic belt. They are located along the prominent divide between the Ofin River valley to the east and the Tano valley to the west. The steep-sided hills are amongst the highest in the region, with relief mostly in the range 400-500m and a maximum elevation of about 730m ASL and the lowest elevations in the valleys mainly in the range 200-250m ASL.

Work on these deposits has been carried out sporadically over many decades. Just after their discovery in the early 1920s, the Geological Survey Department undertook regional work to assess the size and quality of many of the larger deposits in this long string of occurrences. Their work included sinking many pits and shafts at wide (300m) intervals and they came up with an initial size estimate of about 170 M short tons of inferred resources. Sharp cliffs along the edge of the summits of many hills, as well as many pits on the plateau, indicated that the bauxite layers are fairly thick, mostly in the range 7-15m. Some work was also done in the late 1920s by several private sector groups who acquired concessions over parts of the area.

Due to the war and post-war requirements for bauxite, considerable work was carried out in the district in the mid 1940s through to the mid 1950s, mostly by a Montreal-based company, Aluminium Laboratories Limited who had obtained options on several concessions in the area. Their early work focused on the northern part of the district (close to Mpeaso) but their later work included extensive drilling to test the southern occurrences. Ghana Geological Survey Rept 75/2 by G.O. Kesse indicates that well over 300 drill holes were completed along the range of hills by Aluminium Laboratories who were trying to identify the best resources that could form the basis of a national bauxite and alumina industry in the country. In the concessions under their control, mostly at the north end of the district, they estimated there was over 230 Mt of bauxite in the range of 40-50% Al_2O_3 and low silica (less than 3%). This was clearly sufficient to support a long-term industry but the company was unable to proceed.

The area lay dormant until the early 1970s when the Government stepped in and took back the concessions for non-performance with the intention of making the area available for other interested parties. In the meantime, in order to make the area attractive to potential investors, the Geological Survey again carried out extensive work in the southern part of the district, which included over 700 boreholes, mostly on an approx. 150m grid spacing; the total footage drilled was close to 30,000 from which just over 14,000 samples were taken. The principal bauxite occurrences yielded analyses mainly in the range 40-50% Al_2O_3, 20-30% Fe_2O_3, 1-5% SiO_2, 1-2% TiO_2, and 20-30% loss-on-ignition. Resources on the 3 southern hills at Nyinahin were estimated to contain very close to 100 Mt (indicated category).

In the mid-1970s, the Government commissioned a new study on the feasibility of a bauxite/alumina operation based on the Nyinahin resources. The work was carried out by an Hungarian consortium with expertise in the aluminium industry. Their work involved a detailed characterization of the various bauxite deposits along the range and re-confirmation of the resource base using mainly data from previous work. Their work noted that the composition of the bauxite deposits varied a great deal both vertically and horizontally over short distances. The mineralogy of the bauxite is dominated by gibbsite in a variety of grain sizes (20-70 micron), textures and settings; boehmite is present but quite subordinate. Iron oxides are abundant, mainly in the form of hematite with lesser amounts of goethite and limonite; they are generally quite to very fine-grained, mostly in aggregates of grains that are less than 10 micron in diameter. Minor fine-grained silica and kaolinite are present, as are minor accessory minerals such as anatase, rutile, zircon, and tourmaline. The chemical composition of most samples fall in the range noted in the above paragraph.

The Hungarian team examined all of the district with known drill or pit data and came up with measured and indicated resources totaling about 280 Mt; this included about 135 Mt of measured resources contained mainly in the large southern hills whereas the approx. 145 Mt of indicated resource are in the northern hills. These estimates do not include all of the known resources in the area so the overall potential will certainly exceed 300 Mt. After completion of the Hungarian study, the Government was unable to secure financing for the project. That was also at about the time that the huge, high-grade bauxite deposits in the coastal areas of Guinea were being evaluated and eventually developed on a large scale.

ATEWA RANGE – KIBI DEPOSITS (Eastern Region)

The Atewa Range is located in the Kibi District of the Eastern Region, only about 70 km NW of the capital Accra and it is immediately adjacent to the main highway from Accra to Kumasi. It is therefore not surprising that some of the earliest geological traverses by Sir Albert Kitson in 1914 noted large boulders of bauxite along the flanks of the Range. However, it was several decades before the area attracted much attention for bauxite and that came about as a result of plans to build the Akosombo Dam in the late 1950s and early 60s, when the dam became a reality and indigenous sources of bauxite were examined to supply the aluminium manufacturing plant to be built at Tema.

The Atewa Range stands well above the surrounding countryside and is a continuous, steep-sided but flat-topped range that is about 50km long and 10-15km wide. The maximum elevations on the range are over 800m ASL, whereas the nearby lowlands are at about 180-200m ASL. The area has abundant rainfall (1500-2000mm/yr) and is the headwaters for the important Birim and Densu river systems. The area is best known for its extensive alluvial gold resources, which have been mined by local artisans for centuries. Most of the Range is within a large national forest reserve where substantial primary forest is preserved and the area has numerous unstudied archeological sites and a very rich and diverse eco-system.

The flat-topped summit of most of the Range is the remnant of an old erosional surface, probably dating back to the mid or early Tertiary (30-40 Ma), that formed at lower elevations and was subsequently uplifted and eroded. The Tertiary and Recent tropical climate was very favourable for the development of laterite, which is well-developed throughout the district. The laterites are fairly typical for southern Ghana and consist of complex mixtures of mainly iron and aluminium oxides. Underlying the Range are a variety of Birimian metasediments and some mafic volcanic flows and sub-volcanics intrusives. Hence the overlying laterites are also variable in their composition but do include quite large areas dominated by bauxite.

The first real effort to assess the size and quality of the bauxites on the summit of the Atewa Range was by British Aluminium in 1957-58 when they drilled 255 shallow holes (2487m) and sunk 9 large pits to confirm drill indications and to get representative material for metallurgical testwork. Their work was entirely focused on Atewiredu Hill, immediately west of the village of Sagemase, from where an access road was built to the top of the Range. The drilling outlined an indicated resource of about 30 Mt with an average grade of 45% Al_2O_3 and a silica content of 2.6%.

In 1964-65, Kaiser Engineering teamed up with the Ghana Geological Survey to follow up on the work done by British Aluminium to expand and better define the resources at Atewiredu Hill and immediately northwards to areas designated as Asiakwa South and North. Initially, at Asiakwa South, 352 holes (4338m) on a square grid spacing of 75m were completed and these established a measured (proven) resource of just over 17 Mt averaging about 44% Al_2O_3 and just over 3% SiO_2. The Geological Survey expanded this programme in 1966-69 to Asiakwa North where fairly large resources had been previously identified. They completed 270 more boreholes (3569m) and they added another approx. 34.5 Mt of measured and indicated resource averaging 42.5% Al_2O_3, 3.8% SiO_2 and 27.3 % Fe_2O_3.

In 1972, a consortium of major foreign aluminium companies, going by the acronym BASCOL and including the Kaiser group from the USA, was granted a 1-year exclusive exploration licence covering most of the summit areas of the Atewa Range. They completed over 200 drill holes at Asiakwa North to add to the resources defined a few years earlier at Atewirudu Hill and Asiakwa South. They also completed 15 major pits for bulk samples needed for metallurgical tests and density determinations. This work revealed the Asiakwa North bauxite to vary considerably in thickness and composition; the thickest portions are over 12m and they can be as thin as 2-3m. The alumina content is sometimes over 50% (up to a max of about 55%) but mostly is in the range 40-50%, whereas the iron oxide is mainly in the range 20-30%; the silica content is 1-3% and the titanium oxide content is 2-4%. Similar to most bauxite deposits in southern Ghana, the loss on ignition, due to the hydrated iron and aluminium minerals, is 20-30%. The dry weight density determinations are mostly in the range 1.5-1.8.

BASCOL consolidated all the previous work and came up with new resource estimates for the deposits at Atewiredu and Asiakwa. Their total was about 132 M dry short tons (approx. 120 Mt) of measured resources with an average grade of 44% Al_2O_3 and 3% SiO_2, with an average thickness of 9.3m; this utilized a cut-off grade of 40% alumina and 5% silica. Additional indicated and inferred resources in the same northern deposits reveal another approx. 30 M dry short tons. There are also known occurrences in the southern part of the Range and preliminary estimates suggest an inferred potential of around 40 M dry short tons. Thus, the overall resource potential along the summit of the Atewa Range will likely be about 200 Mt of bauxite. At the time, the BASCOL consortium decided that, despite the large resources on the Atewa Range, which is only about 85 km from the Kaiser aluminium plant in Tema, this bauxite was not an ideal source of alumina and they continued to import better grade material from Jamaica.

The Ghana Government was still intent on establishing a more integrated aluminium industry in the country and so, in 1976, they asked the Hungarian parastatal (Chemkomplex) who were working on the Nyinahin deposits, to also assess the bauxite on the Atewa Range. Their work confirmed many similarities with the Nyinahin area in grades, mineralogical and chemical composition, thickness, textural and compositional complexities, and association with underlying kaolinite. At Kibi, the bauxite usually is overlain by soil and a hematitic crust of iron-rich laterite and similar thin (1-2m), iron laterite horizons may be repeated within the 8-12m section of bauxite. Gibbsite is the dominant Al-rich mineral, whereas hematite and goethite are widespread iron oxides; silica/quartz, kaolinite, and anatase (TiO_2) are the main accessory minerals. Their work further confirmed that the bauxite could be used to feed a large (800,000 tpa) alumina plant based in Kibi but financing for the project was never secured.

Since the mid 1970s, there have been repeated efforts by Government to attract private sector groups to undertake a large bauxite/alumina operation utilizing the resources along the Atewa Range. Part of the problem has been that, since the late 1980s, the rapid growth of the gold mining sector, as well as the fairly dramatic expansion in the major urban centres of the country, have taken up whatever excess capacity was previously available from the Akosombo and Kpong hydro-electric dams and the economy in fact suffers from power shortages and rapidly increasing power tariffs. This situation may change significantly with the arrival of natural gas from Nigeria and from the oil and gas discoveries offshore Ghana at the far west end of the country. This could have a very favourable impact on a potential integrated aluminium industry in the country.

OTHER OCCURRENCES

Early in World War II, a very small open-pit operation was started at Mount Ejuanema on the prominent escarpment to the immediate north of Nkawkaw, along the Accra-Kumasi highway and railway. This small bauxite deposit had been known for several decades and had been evaluated in the mid 1920s by the Geological Survey, which established that the deposit was very limited in extent. Despite its small size and mediocre quality, it was well located and therefore of considerable use in the ongoing war effort but it closed immediately after the war in 1945 and it appears to have produced only a few thousand tonnes of ore.

The Mt. Ejuanema deposit occurs as a remnant laterite deposit along the crest of the Kwahu escarpment and underlain entirely by Volta Basin clastic sediments. After the early work by the Geological Survey in the 1920s, the Survey carried out more work in collaboration with a Hungarian expert in 1967-68, who estimated that the overall size of the deposit was in the order of 5 Mt but only about 1 Mt of industrial grade bauxite (48% Al_2O_3, 4% SiO_2, and 23% Fe_2O_3) was apparently available. Similar remnants have been identified further to the SE along the escarpment and although the quality of some of the occurrences appears to be satisfactory, most are limited in extent.
Virtually all of the highest hills in SW Ghana are capped by laterites that are dominantly iron-rich but many of these will include portions that are very high in alumina and suitable for the aluminium industry if sufficient resources are defined. It should also be noted that there are huge volumes of laterite containing high alumina and iron oxide (combined 60-70% Al_2O_3 + Fe_2O_3) in many parts of southern Ghana. If an economical means can be developed to recover high percentages of both of these minerals from the same operation, a very large resource could be defined in this region.

Iron Ore in Ghana

INTRODUCTION

Virtually all iron, steel and many alloyed metals come from iron ore and, despite the very widespread presence of iron in many minerals, the commercial sources of iron ore are very limited and come mainly from concentrations of iron oxides. Needless to say, any modern economy depends greatly on iron and steel products for a vast number of needs relating to infrastructure, manufacturing, mining, agriculture, fishing, housing, transportation, medicine, scientific research, as well as armaments and a host of other uses. Thus, the importance of iron cannot be overstated and it was the breakthrough in learning to make iron implements and weapons that catapulted early, isolated communities into more complex, interdependent societies the world over.

Much later, the ability to make steel and a wide range of ferrous alloys accelerated the growth of large urban communities, national and international transportation systems, military arsenals and globalization in general. Industrialized economies with the capacity to produce a wide range of essential iron and steel products advanced rapidly whereas others lagged behind. Some of the industrialized economies (USA, former Soviet Union) had large domestic supplies of iron ore whereas many European (UK, France, Germany, Italy) and Asian (Japan, South Korea and Taiwan) nations had to import large amounts of iron ores, mainly from lesser developed countries. The dominant/traditional exporters of iron ores have been Australia, Brazil, Canada, and South Africa.

By the beginning of this new millennium, the world economy had been transformed significantly by the emergence of China as a major industrial power and to a lesser degree by the rapid growth in India. The modernization and urbanization of China in an unprecedented short period of time has completely altered the dynamics of the iron ore business. The steel making capacity and demand of China and its Asian neighbours has greatly increased the need for new sources of iron ores. Thus, iron ore deposits have suddenly become increasingly important and many African countries contain significant resources of iron ore, which have been largely undeveloped. Africa is now being explored and courted by virtually all of the industrialized nations in search of new sources of iron ores.

At the same time, most African countries, with the exception of South Africa, have minimal steel-making capabilities and import virtually all of their iron and steel requirements. In order for African economies to advance, it will be essential to have more regional capability to produce a wide range of iron and steel products needed to better develop infrastructure and manufacturing capabilities. It was Dr. Kwame Nkrumah, Ghana's first president, who fervently wished to industrialize the economy and have the capacity to produce most of Ghana's industrial requirements from local resources as much as possible. Thus, in the 1950s and early 1960s, much effort was directed towards assessing local resources, including iron ores.

[Insert of Ghana map showing locations of all deposits]

SHIENI IRON ORE DEPOSITS (Northern Region)

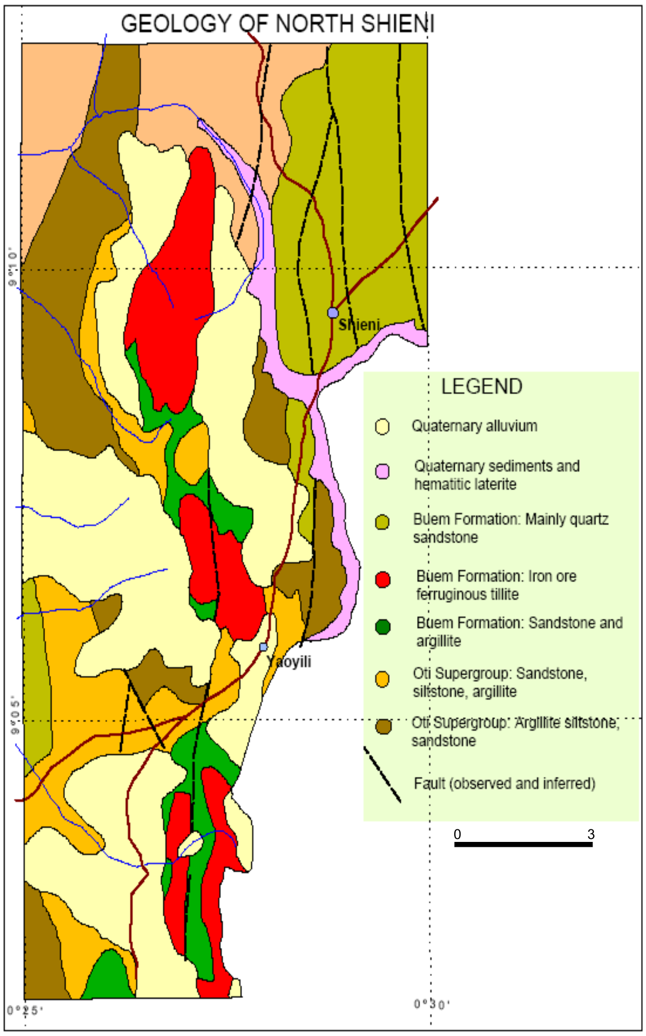
It had long been known that large iron ore deposits are located along the northeastern part of the Togo-Ghana border. These were first described in the early 1900s, prior to World War I, by German geologists exploring in the vicinity of Bassar, Togoland, which was then a German colony. It was not until the late 1920s that geologists from the Geological Survey Department reconnoitered the Ghana side of the border and identified numerous iron ore deposits in the general vicinity of the small village of Shieni, right next to the Togo border. The deposits at the time were too remote and too low grade to be of commercial interest.

The Shieni deposits are part of an iron ore district that can be traced for a distance of about 50km north-south and about 20 km east-west; it includes numerous individual deposits on both sides of the border. Although little real effort has been directed towards properly defining the resource potential of the entire district, it would appear that the collective resource is very likely to exceed 1 billion tonnes and perhaps twice that amount will be more realistic.

The current interpretation by the Ghana Geological Survey is that the Shieni iron ore deposits are part of the Buem Structural Unit, which features Late Proterozoic clastic sediments in shallow, east dipping thrust sheets. These units were thrust westwards during the major Pan-African orogenic event (approx. 600 Ma) on top of other similar Late Proterozoic sediments in the largely undisturbed Volta Basin.

The Ghana Geological Survey carried out fairly detailed evaluation studies at Shieni in the mid 1950s, which included extensive mapping, numerous shallow trenches and 9 diamond drill holes; all of this was focused in the main northern group of occurrences, which seem to be higher grade and have favourable features for mining. Later, in the early 1960s, Soviet technical teams were very active in the area; their work included regional prospecting and stream geochemistry as well as more detailed work on the northern Shieni deposits, including 14 more diamond drill holes. Unfortunately, not all of the Soviet data seems to have been preserved due to their abrupt departure from the country in 1966.

Mapping in the area has outlined extensive and quite complex concentrations of iron oxides, which seem to be largely confined to Late Proterozoic clastic deposits that have been interpreted to be glacial tillites. As noted above, the northern occurrences appear to be the best quality for potential development so most of the past work has been focused on these occurrences. These include 5 separate, but fairly closely spaced deposits over a strike length of about 9km. Most are quite noticeable because they form prominent hog-back ridges with a relief up to about 300m above the nearby valleys.



The deposits appear to occur in a series of parallel and en-echelon synclines with narrow, intervening anticlines. Individual deposits have a strike length in the range 1000-2500m and widths in the range 400-800m. All seem to display shallow dips (30-45^0) on the western flanks and steeper dips (70-90^0) on the eastern flanks. In many cases, the western flanks have dips close to the slopes of the hill-sides.

The surface exposures and trenches indicate quite a variation in the nature and distribution of the iron ore, which has been attributed to varying degrees of replacement of the original Late Proterozoic glacial tillites. The main iron minerals are hematite, hydro-hematite and goethite/ limonite. The other dominant mineral is quartz/silica and the iron and silica minerals are often closely inter-grown. Within the iron-rich sections, units are variously described as thin banded iron ores, thick banded ore, siliceous iron ore, tillite-like massive iron ore, ferruginous tillites, disintegrated ferruginous tillites, and siliceous, jasper-like units. The Soviet work reports variables thicknesses of the iron-rich sections, usually in the range of 40-70m. In the earlier work by Geological Survey, the variable thicknesses of iron-rich units are also evident in both trenches and boreholes where massive ores occur in several bands 3-10m thick within 30-50m individual sections.

The collective resource potential in the North Shieni field is not at all well-established but appears to be at least 300 Mt with an average grade of about 45% Fe; other important constituents include mainly silica (20-40% SiO_2) and alumina (2-8% Al_2O_3). Additional iron ore deposits have been traced many kilometers to the south around Kubalem where they appear to curve eastwards into Togo. The southern deposits are likely to have a tonnage potential in the order of 500 Mt but grades will most likely be lower, probably in the range 25-45% Fe. On the other side of the border, the Togo government has estimated iron ore resources of 500 Mt with an average grade of about 45% Fe. The collective size potential is therefore quite considerable.

The origin of the iron ores is quite speculative and intriguing. Most descriptions suggest that the iron oxides have replaced the tillites on a massive scale and the hydrothermal fluids responsible for the replacement were channeled along N-S faults of regional extent. It may well be that the influx of iron oxides was coincidental with the Late Proterozoic alkali volcanism that has been observed and dated nearby. If this is correct, the Shieni iron ores may belong to the broad type of hydrothermal complexes now often described as iron ore-copper-gold systems and observed at the famous Olympic Dam deposit in South Australia and the Kiruna iron-ore deposit in northern Sweden that has been mined for hundreds of years.
The future development of the iron ores in this large district will depend on several key factors. First, the iron ores will need to be upgraded at site to a product containing at least 55% Fe. Infrastructure in the form of an improved transport system, either by railway or possibly by barging on Lake Volta, will be needed to get the iron ore to a coastal port. A long-term source of inexpensive power would be beneficial and this could come from the Nigerian gas that is now flowing in the offshore pipeline. To maximize the long-term development of the iron ores, it will be vital to work out a master plan for the entire district and it will require real co-operation between the governments of Ghana and Togo.

Ideally, the iron ore could feed a nearby steel-making facility that would meet local and many regional demands. The steel producer could be located along the coast or alternatively, it could be located on the shores of Lake Volta, close to the iron ore deposits. This location would be able to take advantage of the large limestone deposits at Buipe, also on the shores of the lake, and even the manganese deposits located a short distance west of the lake. The limestone and manganese are critical ingredients for a range of steel products.

OPON-MANSI IRON ORE DEPOSITS

Whilst carrying out a regional mapping programme SW of Dunkwa (Western Region) in 1963, the Geological Survey discovered extensive iron-rich laterites capping the ridges between the Opon and Mansi rivers, immediately to the west of the Dunkwa-Takoradi railway line. The very favourable location of these deposits made them a candidate as feedstock for an iron and steel producer, which was something of great interest to the Nkrumah government.

Extensive work was subsequently carried out by US and Soviet geologists under the direction of the Geological Survey. Significant laterites were observed to cap the hills over an intermittent length of 20+km along ridges that have elevations in the range 400-450m ASL and that stand well above (in places approx. 300m) the nearby valleys; much of the ridge areas are within a National Forest Reserve. The iron-rich laterites, which commonly are 10+m thick (up to approx. 30m), overlie mainly Birimian metasediments and volcanics that strike approx. NE and dip moderately to the SE.

Initial estimates for the regional resource potential indicated in the order of 150 Mt with an average grade of just over 50% Fe. Detailed studies were focused on the deposits at Wuowuo Hill, which was accessed by an 8-km road built by the Soviets whose work was cut short in early 1966. Pretty well throughout the 1970s, the Krupp group of Germany carried out many studies on behalf of the Government to assess the Opon-Mansi deposits, especially Wuowuo Hill, as the basis for an integrated iron and steel industry using mainly local inputs.

Krupp's work on Wuowuo Hill included extensive drilling (94 drill holes) and bulk sampling for metallurgical testwork. The drilling and analytical work established a resource base of about 18 Mt with an average grade of 39% Fe, 21-22% Al_2O_3, and 4-5% SiO_2. The mineralogy of the iron ore is dominated by hematite, hydro-hematite and closely related goethite/limonite; the high alumina occurs mainly in gibbsite, a principal mineral of most bauxite deposits. Accessory and minor constituents include quartz, ilmenite, rutile and tourmaline.

The mineralogy of the deposits reflects their origin through prolonged tropical weathering and the process of lateritization dating back millions of years from the early Tertiary to Recent times. At Opon-Mansi, the laterites are mainly iron and alumina rich whereas in other localities they may be more alumina rich and therefore develop bauxite or, in some areas, they may be more manganese rich and form high-grade manganese oxide deposits. Undoubtedly, similar laterite deposits were much more widespread across southern Ghana but now are observed only as only tiny remnants preserved along the crests of the highest hills in the region.

The Krupp studies did confirm that the Opon-Mansi iron-ore (+/- alumina) deposits could form the basis of a local iron and steel industry utilizing the nearby manganese (Nsuta), limestone (Nauli), silica sands (Tarkwa) and locally produced charcoal. Any updated feasibility study on developing the Opon-Mansi iron ore deposit should also assess recovering the alumina-rich minerals (mainly gibbsite) as a by-product. Unfortunately, financing for such an ambitious undertaking was never secured. Nevertheless, the location close to the railway and the Port of Takoradi, as well as the availability of important nearby inputs, remains very favourable and the discovery of off-shore oil and gas to the west of Cape Three Points should provide a long-term source of power in this region, which would greatly benefit any major industrial project established in the area.

OTHER IRON ORE DEPOSITS

There are quite a few other iron-ore deposits scattered around Ghana but these are all relatively small and would perhaps only be important if an iron and steel manufacturing facility were already established in the area. Most of these occurrences are in southern Ghana and they are of the lateritic type found on almost all of the highest hills in the region. Therefore, they are usually small in size but in some areas, the grades for limited tonnages (1-5 Mt) will be about 50% Fe and, if treated on site by fairly rudimentary methods, they could be up-graded to 55+% Fe. It should also be emphasized that, as noted above, almost all the lateritic iron ore deposits contain substantial alumina-rich oxides, including substantial gibbsite the main mineral in bauxite and conversely, virtually all of the main lateritic bauxite deposits contain abundant iron oxides (mostly hematite and goethite/limonite). Iron oxides could be recovered as a by-product from a bauxite operation.

At the far north of Ghana, very close to the border with Burkina Faso, there is a mafic-ultramafic plutonic complex in the Pudo Hills (NE corner of the Upper West Region) that contains substantial titanium-rich iron ore. These iron ores were spotted by Sir Albert Kitson, the first Director of the Geological Survey Dept., in early 1927 whilst on a regional traverse. Subsequently, work was carried out periodically (mainly 1950s and 60s) in the vicinity by the Geological Survey, including mapping, sampling and ground geophysics. The countryrock is mainly Birimian-age biotite gneiss intruded by intermediate granitoid (recently age-dated at 2162 +/-1 Ma) and the large Pudo complex that appears to be mainly norite with segregated bands of ilmenite-rich magnetite probably formed by gravitational settling.

The Pudo complex appears not unlike some of the mafic intrusions in southern Ghana, such as the Mpohor intrusion, which also features extensive bands of titaniferous magnetite formed by gravitational settling. They may also be of similar vintage to the extensive 'epidiorites' observed in many parts of the Ashanti Belt, which contain concentrations of titanium and iron oxides and which are clearly pre- Eburnean in age. The bands of magnetite at Pudo can be traced along strike for up to 5km and they occur in two main localities north and south of the village of Pudo. Where observed in bedrock exposures, the individual bands of magnetite are rarely more than 1m thick and although there are multiple bands in places, the overall cumulative widths are generally less than 10m. Thus the size potential is quite modest; a preliminary inferred resource of about 3.5 and 1 Mt respectively for the North and South Pudo areas was estimated by the Geological Survey with average grades probably in the range 20-30% Fe and 3-5% Ti. More detailed exploration in the area would be warranted in order to see if any wider bands of better grade material are present.