AN ABUNDANCE OF LITHIUM

R. Keith Evans

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Keith Evans, a geologist by profession, first became involved in the lithium business in the early 1970's when, on behalf of Selection Trust Ltd., was asked to evaluate the future potential of Bikita Minerals in what, at that time, was Southern Rhodesia (later Zimbabwe). Selection Trust was the majority owner of the operation which, prior to the imposition of United Nations sanctions, had been the dominant producer of lithium ores for direct usage in the glass and ceramics industry.
Subsequently, he joined Lithium Corporation of America, the then leading lithium chemical producer and later moved to Amax Exploration.
On behalf of Amax and a Chilean partner he negotiated with Corfo, a Chilean government entity, the rights to evaluate and develop that part of the Salar de Atacama that had not been leased to the Foote Mineral Company.
He was responsible for all aspects of the evaluation but when Amax decided not to proceed with the project it was acquired by Sociedad Quimica y Minera (SQM) and the company is now the world's largest lithium chemicals producer.
Throughout his career in the lithium industry it was his responsibility to monitor industry developments particularly in respect of new resources and he has continued as a consultant in a number of industrial minerals.

ABSTRACT

In 1976 a National Research Council Panel estimated that Western World lithium reserves and resources totaled 10.6 million tonnes as elemental lithium.

Subsequent discoveries, particularly in brines in the southern Andes and the plateaus of western China and Tibet have increased the tonnages significantly. Geothermal brines and lithium bearing clays add to the total.

This current estimate totals 28.4 million tonnes Li equivalent to more than 150.0 million tonnes of lithium carbonate of which nearly 14.0 million tonnes lithium (about 74.0 million tonnes of carbonate) are at active or proposed operations.

This can be compared with current demand for lithium chemicals which approximates to 84,000 tonnes as lithium carbonate equivalents (16,000 tonnes Li).

Concerns regarding lithium availability for hybrid or electric vehicle batteries or other foreseeable applications are unfounded.

I INTRODUCTION

In 1975 the United States Geological Survey convened a symposium in Golden, Colorado, on lithium demand and resources prompted by the premise that lithium resources would be inadequate to meet future demand in fusion power generation (expected from the Year 2000 onward!) and in load leveling storage batteries. Demand estimates were astronomic and in the light of these projections the availability of adequate reserves was seriously questioned. In the introduction to the symposium reference was made to the "gravity" of the impending shortage of lithium. (Anon 1976)

Fortunately, shortly afterwards, at the request of the United States Energy Research and Development Administration, the National Academy of Sciences and Engineering formed a National Research Council Committee on Nuclear and Alternative Energy Systems (CONEAS) to report on the role of nuclear power in the context of alternative energy systems in the time period 1985 to 2010. CONEAS was organized into four main panels and twenty-six sub panels and the Lithium Sub Panel was one of these asked to report on raw material availability.

This group was chaired by Dr. Thomas Kesler, formerly with the USGS and the leading authority on the North Carolina tin-spodumene belt the, then, dominant source of lithium, Dr. James Vine of the USGS and the head of its Lithium Resource Appraisal Group, Dr. Ihor Kunasz of the Foote Mineral Company and the writer representing Lithium Corporation of America. The panel reported in 1976 (Evans, 1978) and some of the figures used in this current paper are based on that report.

The tonnage estimated in the panel report of 10.65 million tonnes of Li was in respect of the Western World as little data were available in respect of Russia and China.

In 1985, fresh concerns about lithium availability arose from a different group of researchers and aluminium producers when it seemed a possibility that lithium-aluminium alloys for aircraft would create a major demand and the writer produced an updated report based on new discoveries in the preceding ten years (Evans 1986).

Additions to the 1978 paper included the estimated reserves in the Greenbushes spodumene pegmatite in Western Australia, the brines of the Salar de Uyuni in Bolivia, the lithium in geothermal brines in Southern California and the lithium contained in hectorite deposits in the Western USA.

Recently, concern has again been expressed about lithium availability (Tahil, 2007) because of the potential very large scale use of lithium carbonate, in particular, in lithium-ion batteries in hybrid and all-electric motor vehicles and this has precipitated the preparation of this report.

II LITHIUM SOURCES

Actual and potential sources of lithium are from pegmatites, continental brines, geothermal brines, oilfield brines and the clay mineral hectorite.

PEGMATITES - are course grained igneous rocks formed by the crystallization of post magmatic fluids. They occur in close proximity to large magmatic intrusions. Lithium containing pegmatites are relatively rare and are most frequently associated with tin and tantalite. Many of the lithium 'discoveries' resulted from the exploration for these associated minerals.

The principal lithium pegmatite minerals are spodumene, petalite (both lithium-aluminium silicates) and lepidolite (a lithium mica) which normally contains minor quantities of cesium, rubidium and fluorine. All have been used directly in the glass and ceramic industries provided the iron content is low and all have been used as the feedstock for the production of lithium chemicals. Spodumene, as a concentrate, is still used in China for lithium chemical production and new production is planned in Europe and Australia.

CONTINENTAL BRINES - these brines with the lithium derived mainly from the leaching of volcanic rocks vary greatly in lithium content largely as a result of the extent to which they have been subject to solar evaporation. They range from between 30 to 60 ppm in the Great Salt Lake, Utah, where the evaporation rates are modest and dilution is constant due to the high volume of fresh water inflow, through the subsurface brines in Searles Lake California (a former location of lithium production) and Silver Peak, Nevada (a current source) to the high altitude salars in Bolivia, Argentina, Chile, Tibet and China where lithium concentrations can be very high.

GEOTHERMAL BRINES - the author is not aware of any publications that provide a listing of the lithium content of all known geothermal brines. Small quantities are contained in brines at Wairakei, New Zealand (13ppm Li) at the Reykanes Field (8ppm) and other areas in Iceland and at El Tatio in Chile (47ppm). The most attractive known occurrences are in the the Brawley area south of the Salton Sea in Southern California.

OILFIELD BRINES - large tonnages of lithium are contained in oil field brines in North Dakota, Wyoming, Oklahoma, east Texas and Arkansas where brines grading up to 700mg/lt are known to exist. Other lithium brines exist in the Paradox Basin, Utah and but the author is unaware of any global review of the potential.

HECTORITE CLAYS - hectorite is a magnesium lithium smectite and the clay is found in a number of areas in the western United States. The largest known deposit is associated with the volcanic rocks of the McDermitt caldera that straddles the Nevada/Oregon border where it occurs in a series of elongate lenses. Current drilling is confirming earlier work that indicated very large tonnages of contained lithium.

III MAJOR INDUSTRY CHANGES

At the time of the National Research Council report the production of lithium chemicals was a duopoly in the Western world and demand at that time approximated to 3,200 tonnes/year of Li. Little was known about Russian and Chinese production and reserves.

The two main producers were Lithium Corporation of America (LCA) and the Foote Mineral Company. Both processed spodumene concentrates from their mines near Bessemer City and Kings Mountain, North Carolina.

In 1975 Foote, then owned by Cyprus Minerals, signed an agreement with CORFO, a Chilean Government agency and owner of the mineral claims covering the nucleus of the Salar de Atacama to evaluate the brine deposit there. At the end of the evaluation the company was allowed to lease a percentage of the claims. Sociedad Chileno de Litio was formed and production commenced in 1984. Foote/Cyprus was subsequently purchased by Chemetall and later by Rockwood Holdings.

In 1980, Amax Exploration visited the Salar as part of a global search for potash but on discovering that the Foote agreement granted them exclusive rights for lithium recovery for only eight years pressed for the right to co-produce lithium. In 1984 CORFO invited bids for the development of much of the remainder of the Salar's nucleus. Amax were successful in bidding against LCA (which, by then had been purchased by FMC Corp.) but Amax, following the completion of an evaluation programme, decided to dispose of its interest and this was acquired by Socieded Quimica y Minera (SQM) a major producer of iodine and sodium nitrate. SQM came into production at the Salar in 1997. The production duopoly was now broken and to acquire market share and with its low costs SQM substantially reduced the price of lithium carbonate.

Having lost the bid in Chile, FMC turned its attention to the Salar de Uyuni in Bolivia but failed in its negotiations with the Government there but successfully negotiated with the Argentinian authorities for rights to the Salar de Hombre Muerto. Although a much smaller salar the brine is an extremely 'clean' one and produced a quality of lithium chloride unavailable elsewhere. However, both capital and operating costs were much greater than anticipated and carbonate production was suspended for several years. FMC became reliant upon SQM for carbonate.

The North Carolina pegmatite mines closed with the development of the lower cost reserves in Chile and Argentina.

Another producer Admiralty Resources, plans to come on stream in 2008 from shallow brines at the Salar de Rincon in Argentina.

In the early 2000's after the evaluation of the very large brine deposits in the Qaidam Basin in Northwest China, a technical breakthrough was achieved in the processing of brines with a high magnesium content. Subsequently, major discoveries were made on the Tibet Plateau. Prior to the brine developments China produced lithium chemicals from domestic pegmatite sources and imported spodumene concentrates.

Since the National Research Council report other low iron sources of lithium ore for direct usage have been developed so now there are three – Bikita in Zimbabwe, Bernic Lake in Canada and Greenbushes in Australia. The last of these attempted to enter the chemical business but failed. Direct usage ores have some significance in chemical demand in that they compete with carbonate in certain applications.

IV PRODUCTION COST COMPONENTS

In the case of production from pegmatites, assuming the most common acid leach process is used, they comprise mining, beneficiation to a moderate or high grade of concentrate, calcination to produce acid-leachable beta spodumene, reaction with sulphuric acid and the conversion of the lithium sulphate solution with sodium carbonate. The costs of acid, soda ash and energy are a very significant percentage of total costs but they can be partly offset if a market exists for the sodium sulfate by-product.

In the case of hectorite clays, geothermal brines and oilfield brines lithium recovery costs have not been developed but work is current on the first two of these potential sources.

In the case of continental brines which are the current major source costs, probably, vary greatly. As with the case of pegmatites the cost of soda ash to convert lithium chloride to lithium carbonate is very significant. Brine grades vary greatly ranging currently in the Andes, from approximately 0.3% Li at the SQM operation in Chile to 0.062% and 0.034% at the two Argentinian salares of Hombre Muerto and Rincon respectively.

The most deleterious element in the brine is magnesium and the magnesium/lithium ratio is relatively low at the Salar de Atacama, very low at the Salar de Hombre Muerto and high at the Salar de Rincon. The largest of the Chinese brine deposits also has a very high ratio and these brines need more complex processing.

The other important factor in the brine chemistry is the presence or not of other recoverable products.

In Chile, Rockwood Holdings, now the owner of Chemetall who purchased Foote/Cyprus recover moderate tonnages of potassium chloride as a co-product at their operation and SQM recover much larger tonnages together with potassium sulphate and boric acid. Most of SQM's potassium chloride is converted to much higher value potassium nitrate using nitrates from company owned deposits located between the salares and the Pacific coast.

At the Salar de Rincon potash recovery is planned and most of the Chinese salars contain economic concentrations of potassium and boron.

Another factor affecting capital costs apart from brine grade is the net evaporation rate which determines the area of the evaporation ponds necessary to increase the grade of the plant feed. These are a major capital cost but not a factor at the FMC operation where the lithium chloride is recovered directly from the <u>in situ</u> brine.

In the case of the one geothermal source discussed later the brine is rich in zinc a co-product as well as lithium and is a major producer of electric power but, as is with the case of oil field brines and hectorites, lithium recovery costs have not been determined.

A final cost factor is location. Some deposits are extremely remote.

V COUNTRY REVIEW

(a) The United States

Pegmatites:

The two North Carolina operations closed with the development of lower cost sources in Chile but could, should a massive demand materialize and prices rise as a result, be reactivated.

Based on figures used in the Lithium Panel report and later reserve data it is estimated, very approximately, that the FMC and former Foote operations contained reserves of 80,000 and 150,000 tonnes Li respectively at the time both operations were closed.

The Panel, based principally on Kesler's very extensive work along the 48km long belt estimated a potential recoverable resource down to a depth of 1,500 metres of 375 million tonnes of ore at a grade typical of the area thus containing 2.6 million tonnes Li.

Other known pegmatite sources are small.

Continental Brines:

The Panel report listed tonnages for three brines – at Searles Lake, California, at Silver Peak, Nevada and the Great Salt Lake, Utah.

At Searles Lake lithium was recovered as a by-product from the commercial production of soda ash, potash and borax. The lithium was essentially a contaminant and with a process modification production ceased in 1978. It is highly improbable that lithium recovery will take place in the future. Silver Peak commenced production in the 1960's pumping brines varying from 100 to 300 ppm Li. It continues to operate and the remaining economic reserves are estimated at 40,000 tonnes Li.

In the Great Salt Lake the overall tonnage of contained lithium approximates to 520,000 tonnes but the grade is very much lower than other brines considered as potential reserves in this report.

Geothermal Brines:

At the Salton Sea KGRA in southern California a brine with very high concentrations of potash, lithium, boron, zinc and lead is used to produce 288 megawatts of electric power.

A 30,000 tpa high grade zinc plant based on the brine has experienced technical problems but the brine also grades about 200 ppm Li and the throughput contains approximately 16,000 tpa Li. (William Bourcier, Lawrence Livermore National Laboratory, personal communication). Earlier (Duyvestein, 1992) calculated a similar figure of approximately 11,900 short tons of carbonate per 50 MW of capacity.

To put a reserve tonnage to the annual rate a 20 year life is assumed to give a figure of 316,000 tonnes Li.

There are other sites in the area with high lithium values.

Further north at the Mammoth Lakes geothermal field with a much lower lithium concentration, Lawrence Livermore Labs have a current project aimed at silica recovery which would be a first step in recovering lithium from brines of this nature

Oilfield Brines:

Collins (1978) estimated a possible reserve of 0.75 million tonnes of Li in one tenth of the area underlain by the Smackover Formation which extends through North Dakota, Wyoming, Oklahoma, east Texas and Arkansas. Other lithium-containing brines exist in the Paradox Basin, Utah.

Hectorites:

At the McDermitt Caldera on the Oregon/Nevada border, Western Uranium Corporation are re-examining seven lenses of hectorite clay originally drilled by Chevron Resources.

Drilling at the most southerly site, the PCD lens, is confirming the tonnage and grade indicated by Chevron. This lens has a length of about 2 kms, a width of approximately one kilometer and a thickness of 100 metres under shallow overburden. Higher grade portions of the deposit grade over 0.35% Li and the cut off used in the reserve calculation is 0.275% Li.

Chevron reported that the total resource contained 23.9 billion lbs of carbonate – 2 million tonnes of Li and test work on recovery methods is currently being undertaken.

Hectorites are known to occur elsewhere in the western United States but no reserve data exist.

(b) Canada

Pegmatites:

The underground mining operation formerly owned by the Sullivan Mining Group located near Barraute, Quebec, supplied spodumene concentrate to Lithium Corporation of America to help satisfy the US Atomic Energy Commission's lithium hydroxide purchasing contract in the 1950's.

Subsequently, the company produced a limited range of lithium chemicals but with the ending of the USAEC contract prices had plummeted. The deposit has recently been acquired by Black Pearl Minerals. Reserves are stated to total approximately 90,000 tonnes Li.

Cabot Corp's underground mine at Bernic Lake, was originally developed as a tantalite operation but, now also produces 20,000 (?) tpa of lithium concentrates for direct usage in the glass and glass ceramic industry. The zoned pegmatite also hosts the world's largest reserve of pollucite from which it produces a range of cesium chemicals.

Current reserves (Gary Poetschke, personal communication) total 18, 600 tonnes Li.

Numerous other pegmatites have been partly explored in Quebec, Manitoba and Ontario including Snow Lake (26,000 tonnes Li), La Motte (23,000 tonnes Li), Separation Rapids (56,000 tonnes Li), Wekusko Lake (28,000 tonnes Li) and Sirmac Lake (3,000 tonnes Li) – a total of 147,000 tonnes.

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Pegmatites:

Prior to the imposition by the United Nations of economic sanctions against Rhodesia, Bikita Minerals was the dominant source of lithium minerals for direct use in glass, glass ceramics and enamels because of the low iron content of the minerals.

The deposit has an exceptionally high grade and comprises a classic zoned pegmatite at its southern end passing northwards into a complex mixture of petalite, quartz-spodumene intergrowth and small quantities of eucryptite. The lepidolite in the zoned section provided the feed for the production of about 30% of the United States Atomic Energy Commission's lithium hydroxide stockpile. The deposit was initially evaluated on the basis that products would be hand-picked at +75mm and +25mm so all ore with smaller crystal sizes were ignored. Thus long sections of the strike length of the main pegmatite and a parallel spodumene pegmatite were not evaluated. Currently, the different minerals are separated by a heavy medium system with stockpiles of undersized material from earlier picking as the principal source.

Proved, probable and possible resources (grading 1.4% Li) were estimated by the Panel at 56,700 tonnes Li.

There is considerable upside potential in this figure and numerous petalite-containing pegmatites are known in Zimbabwe and there is no published data on reserves at the large Kamitivi tin-spodumene deposit located in the northwest of the country.

(d) Zaire

Pegmatites:

The largest known lithium-containing pegmatites occur in the vicinity of Manono. Each of a pair has a length of 5,000 metres and a width of approximately 400 metres. The weathered zone has been worked for tin and columbite .

Assuming a depth of only 50 metres the pegmatites could contain 2.3 million tonnes of Li.

(e) Australia

Pegmatites:

The Greenbushes pegmatite was first mined for tin and tantalite in the late 1880's with operations restricted to the weathered surface material. Deeper exploration a century later revealed the presence of spodumene.

The operation, which has changed ownership many times is now owned by Talison Minerals and is the world's largest producer of low-iron content spodumene concentrates at a variety of grades. Concentrates, until recently at least, are also shipped to China for lithium chemical production there although the company's own efforts to produce chemicals in the 1970's failed.

The pegmatite has a strike length of 3 kms and has not been fully explored. The Sons of Gwalia Annual Report for 2003 stated proved, probable and possible reserves of 223,000 tonnes Li.

At Mount Marion, also in Western Australia, Roberts (2004) reported on a group of deposits with total reserves of 19,800 tonnes Li.

Galaxy Resources is currently undertaking an evaluation of a spodumene deposit at Mount Catlin near Ravensthorpe. The company hopes to come on stream with lithium carbonate production in 2010 from reserves of 20,000 tonnes of lithium.

Queensland Gold & Minerals is currently exploring for pegmatites near Georgetown in Queensland.

(f) Europe

Pegmatites:

The Koralpa deposit located 20 km west of Wolfsburg in Austria, has been explored to a depth of 450 metres and contains approximately 100,000 tonnes Li.

In Finland, the Larritta deposit contains sufficient ore to allow the production of 6,000 tpa carbonate for 15 years with plant construction scheduled for 2008. The reserve is roughly estimated at 14,000 tonnes Li.
The property is owned by Keliber Resources in which Nordic Resources has a 60% interest.

(g) Russia

Pegmatites:

Most pegmatites in Russia are tantalite–containing and Roskill Information Services lists the following larger ones. None appears to be mined currently.

Kolmozerskoe	600,000 + tonnes Li_20
Polmostundrovskoe)	
Ulug-Tanzek)	
Goltsovoe)	Each 300,000 to 600,000 tonnes Li_20
Urikskoe)	

Together they could contain very approximately 1,000,000 tonnes lithium.

(h) Brazil

Pegmatites:

Lithium bearing pegmatites occur in Minas Gerais and Ceara. Tonnages are modest and Ramos (2001) reported reserves of 85,000 tonnes Li.

(i) Bolivia

Continental Brines:

The Salar de Uyuni in Bolivia, at an altitude of 3,650 metres covers an area of 9,000 Km^2. Unlike the major lithium containing salares in Chile and Argentina it is completely flat due to annual flooding.

Ballivian and Risacher (1981) reported on brine grades of 0.035% Li and 0.72%K. Grades are highest in the southeastern portion of the salar. They calculated total lithium reserves as 5,500,000 tonnes.

The magnesium/lithium ratio is high at 22/1.

Other salares, also found as the result of shrinkage by evaporation from a Lake Minchin of Pleistocene age, include the large salares of Emprexa and Coiposa with spot samples grading up to 370 and 580 ppm Li respectively.

(h) Argentinia

Continental Brines:

After failing to negotiate a satisfactory agreement with the Bolivian Government regarding the possible development of the Salar de Uyuni, FMC, in 1995, negotiated rights to the Salar de Hombre Muerto in Argentina.

The salar, with a salt nucleus covering 280km^2 but at an altitude of over 4,000 metres has a relatively low lithium content but with a very low concentration of "impurities", in particular an exceptionally low magnesium/lithium ratio of only 1.37/1.

The company opted for a proprietary recovery technique involving selective absorption from in-situ brine. There were major capital and operating cost over-runs and carbonate production was suspended for a few years in the early 2000's although chloride production continued. The company became reliant upon Chile's SQM for carbonate but this contract is thought to have expired in 2007.

The brine grades 0.062% Li and proved and probable reserves to a depth of 70m total 850,000 tonnes.

Admiralty Resources, an Australian company plans to commence production of carbonate, chloride and hydroxide in 2008 from the Salar de Rincon. The company will also produce potash at an initial rate of about 60,000 tpa.

The salar is located at an altitude of 3,740 metres. The salt nucleus covers 280km^2 and the brine grades 0.033%Li and 0.624%K. The Mg/Li ratio is about 8.6/1.

Proved and probable <u>insitu</u> reserves are 1,860,000 tonnes Li.

Numerous other salares exist in the Argentinian altiplano and these are listed below –

	Area Km^2	Reputed av.grade (mg/lt)
Pastos Grandes	29	384
Centenario	59	231
Rotones	38	461
Pazuelos	57	257
Cauchari	44	414
Olaroz	140	306
Antofalla	518	150

The extent to which these salares have been studied is not known. For comparative purposes, Rincon concentrations (expressed as mg/lt) ranged from 370 to 456.

(k) Chile

Continental Brines:

The Salar de Atacama, at an altitude of 2,300 metres, is located approximately 200 kms inland from the Pacific coast. The basin covers an area of about 3,000 km^2 with a salt nucleus covering 1,400 km^2. At the northern end of the nucleus a drill hole was still in salt when terminated at 1,000 metres.

The Salar was first developed by Foote Minerals in partnership with CORFO, a Government agency, in 1984. Subsequently CORFO sold its interest to Foote and later Foote was acquired by Cyprus Minerals then by Chemetall and finally by Rockwood Holdings.

To the writers knowledge the reserve data were never published but are estimated at 500,000 tonnes Li prior to the commencement of production. The company co-produces about 80,000 tpa of potassium chloride.

In 1986, Amax Exploration together with a Chilean partner reached an agreement with CORFO regarding the possible development of much of the rest of the salar but their rights were later acquired by Sociedad Quimica y Minera (SQM) a major producer of nitrates and iodine.

The initial reserves, over 790km^2, were calculated at 26.0 million tonnes of potassium and 1.8 million tonnes of lithium at an average grade of 0.18%Li. These were in respect of the uppermost 40 metres of the aquifer.

SQM developed the project in two phases. The first in the area of highest grades of potassium for the production of potassium chloride and lithium, the second in an area of high sulphate values from which they recover potassium sulphate and boric acid. Lithium, currently, is recovered only from the more southerly well field/solar pond system although the feed grade at the northern location, at about 0.11% Li is considerably higher than those at the Argentinian salares.

Large quantities of lithium are returned to the salar as the quantities of brine pumped to produce in excess of 800,000 tpa of the two potash products contain much more lithium than the installed lithium pond and plant capacity.

In 2008 SQM (personal communication) revised the reserve estimate for its block of claims resulting from the inclusion of brine to a depth of 200 metres. This new estimate is for 77.2 million tonnes of potassium and 6.0 million tonnes Li.

The total reserves of the Salar de Atacama are unknown. In addition to the tonnages beneath the Rockwood and SQM mining claims covering 957km^2, there are "buffer zones" between the properties covering approximately 100 km^2 and there are unclaimed areas to the north of the SQM claims with lithium values in excess of those in the Argentinian salares. A tentative total for these other areas is 400,000 tonnes Li taking the total to 6.9 million tonnes.

Other Chilean salares includingPedernales, Punta Negra, Maricunga and Incahuasi, are lithium containing.

(l) China

Changing names and ownerships together with differing reserve estimates for the same deposits by different authorities reduce the reliabilities of the estimates contained in this paper. Hopefully, a more accurate estimate will emerge in time.

Pegmatites:

Major known pegmatites are Jiajika now owned by Sichuan Mineral Industry (480,000 Li), Maerkang (reserves variously reported at 80,000 and 225,000 tonnes Li) owned by Sichuan Ni and Co, , Daoxian (125,000 tonnes) and Lushi (9,000 tonnes) owned by Sterling Group Ventures and Sichuan Dexin's mine at Jumehuan (50,000 tonnes). Reserve information in respect of other deposits including Ningdu, Kokotay is not available.

A conservative estimate of Chinese pegmatite reserves in 750,000 tonnes and many of these sources provide feed for chemical production.

Continental Brines:

Located in the Qaidam Basin in Qinghai Province are approximately 33 saline lakes. The first to be developed was Chaeran, one of a complex of nine lakes and is now the principal source of potash in China. The company, Qinghai Salt Lake Potash Co. has recently announced plans to recover lithium from the bitterns from the potash operation. The grade and tonnage of the bitterns are not known. Production of lithium from other lakes in the area was delayed because of the technical problems associated with brines with magnesium/lithium ratios as high as between 40 and 60/1. However, CITIC is now coming on stream at the Taijanaier Lakes where reserves are stated to total 940,000 tonnes Li.

Figures as high as 3.3 million tonnes of lithium have been quoted for the reserves of the Qaidam Basin as a whole but specific reserve data is lacking.

A larger number of saline lakes exist on the Tibetan Plateau.

At Zhabuye (also known as Chabyer?) Salt Lake production started in 2005 from a brine grading 0.12%Li. The company claims a reserve of 1.53 million tonnes Li (8.3 million tonnes of carbonate) but other sources say that the tonnage is significantly lower.

Sterling Group Ventures estimate reserves at Dangxiongscuo (DXC) Salt Lake, which they intend developing as 170,000 tonnes Li.

A total brine reserve of 2.6 million tonnes is estimated for China but it seems probable that this figure could increase substantially with more information.

VI RESERVE AND RESOURCE SUMMARY

In the National Research Council report the authors adopted their own definitions of reserves and resources ranging from reserves proven by systematic exploration to resources where economic lithium extraction was probably dependent upon the marketing of co-products or the development of new technologies.

Stricter classifications require that the term 'reserves' apply only to material that can be economically produced at the time of determination. The term also implies that the material can be extracted with existing technology at a specific price-usually the prevailing market price.

Neither technologies nor prices are 'fixed' and this report is written at a time when a major increase in demand seems a strong possibility.

Potential large scale consumers need to know what could be available over a long period whether a particular source is fully proven or not.

The report lists a total of 28.5 million tonnes of lithium, equivalent to nearly 150.0 million tonnes of lithium carbonate – equal to 1775 years of supply at the current rate of demand (approximately 16,000 tpa Li).

Lithium in pegmatites, continental brines, geothermal brines, oilfield brines and hectorites total 7.6 million, 17.7 million, 0.3 million, 0.75 million and 2.0 million tonnes respectively.

Lithium at current or planned pegmatite operations, assuming that 60% of the Chinese pegmatites are active, totals 840,000 tonnes and at active or proposed brine operation totals 12.25 million tonnes.

TABLE I PEGMATITES

Pegmatites:	Tonnes Li
North Carolina Former operations	230,000
North Carolina Undeveloped	2,600,000 *
Barraute, Quebec	90,000
Bernic Lake, Manitoba	18,600
Others, Canada	147,000
Bikita, Zimbabwe	56,700 *
Manono, Zaire	2,300,000 *
Greenbushes, Western Australia	223,000
Mount Marion, Western Australia	19,800
Mount Catlin, Western Australia	20,000
Koralpa, Austria	100,000
Larritta, Finland	14,000
Various, Russia	1,000,000
Brazil, Minas Gerais & Ceara	85,000
China	750,000

* Tonnages in the 1976 report reduced by 25% for open pit and 50% for underground mining

TABLE II BRINES AND HECTORITE

Continental Brines:	
Silver Peak, Nevada	40,000
Salar de Uyuni, Bolivia	5,500,000
Salar de Hombre Muerto, Argentina	850,000
Salar de Rincon, Argentina	1,860,000
Salar de Atacama, Chile	6,900,000
China & Tibet	2,600,000

Geothermal Brines:

Brawley, Southern California	316,000

Oilfield Brines:

Smackover Formation USA	750,000

Hectorites:

McDermitt Caldera Oregon/Nevada	2,000,000

In the 1976 report the figures for pegmatite reserves and resources represented in situ tonnages reduced by 75% for open-pittable deposits and 50% for probably underground operations. The Panel estimated that these deductions were sufficiently large to cover all mining, concentrating and chemical processing losses. These sources are indicated by an asterisk in Table I.

In this paper all other tonnages are in situ tonnages.

For other pegmatites the deductions should be comparable but for brines the recoveries will vary considerably. In the case of continental brines initially processed by solar concentration and involving precipitation of salts such as sodium chloride and potassium chloride the initial 'loss' of brine entrained in the precipitated salt is substantial. However, this is not a permanent loss. The chemistry and nature of the precipitated salts varies with the brine feed so the losses will vary at different operations. At the Salar de Hombre Muerto in Argentina there are no entrainment losses.

Losses associated with the potential recovery of lithium from geothermal and oilfield brines and from hectorites are not known yet.

Regarding production costs, evidence indicates that those at the Salar de Atacama are the lowest and that brines with a high magnesium content will incur higher costs. Pegmatites, based on the abandonment of North Carolina are obviously a more expensive source but with lithium carbonate prices now double those that were current when the North American producers moved south, Chinese producers may not have to abandon their pegmatite sources as a result of being uneconomic. Two non-Chinese companies are considering production from spodumene.

Costs from geothermal brines, oilfield brines and hectorities have not yet been determined.

The tonnages listed are large but they don't represent the total lithium that may become available. Few, if any, known pegmatites have been fully explored, more remain to be discovered. Only one oilfield brine is included in the total, only one geothermal brine and only one hectorite deposit is included.

VII REFERENCES

Anon (1976) "Lithium Resources & Requirements by the Year 2000" U.S.G.S. Professional Paper 1005. James D. Vine, Editor.

Ballivian, O., and Risacher, F. (1981) "Los Salares Altiplano Boliviano" O.R.S.T.O.M. Paris.

Collins, A.G. (1976) "Lithium Abundance in Oilfield Waters" U.S.G.S. Professional Paper 1005.

Duyvesterin, W.P.C. (1972) "Recovery of Base Metals from Geothermal Brines" Geothermics Journal of Geothermal Research and its Applications, Vol.21. No.5/6 Oct-Dec.

Evans, R.K. (1978) "Lithium Reserves and Resources" Energy, Vol.3. No.3.

Evans, R.K. (1986) "Western World Lithium Reserves and Resources", The Institute of Metals. Aluminium-Lithium Alloys III. Proceedings of the 1985 Conference.

Roberts, F.I. (2004) "Mineralization of the Woolgangie-Yilma Area, Eastern Goldfields Granite-Greenstone Terraine" Geological Survey Western Australia, Record 2004/6

Tahil, W. (2007) "The Trouble with Lithium" Meridian International Research

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