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The enigma of the Bario salt produced in the highlands of northern Sarawak

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Abstract: The Bario/Kelabit Highlands, located in northern Sarawak is famous for its rice. One of Bario's hidden treasures, however, is its salt, produced from the many salt springs in the area but sold in small quantities at the local marketplace such that its existence is not well known outside of Sarawak. The Bario salt is probably of non-marine origin but its actual origin is not clear. A new salt analysis, in the context with older salt spring data, has enabled a comparison with other non-marine salts. In particular, the presence of borate and lithium points to potential affinities with non-marine highland salts, such as those found in Argentina, Bolivia, Nevada and Tibet, as well as with phreatic brine salt such as the Jadar deposit in Serbia. The marked content of iodine makes allusion to brines in the vicinity of hydrocarbon-bearing reservoirs. Given that the Bario salt contains hardly any sulphate, and very little calcium, the source of the salt is unlikely to be an evaporite-bearing rock in the subsurface as previously thought. Nonetheless, there should be more fieldwork conducted and analyses made on the highland salt deposits and associated brines in northern Sarawak to provide a better understanding of their geochemical composition and origin.

Keywords: Malaysia, Sarawak, Bario, Kelabit, saltwater spring, salt composition

INTRODUCTION

The exploration for lithium, a highly sought-after metal in the context of electricity storage, has prompted renewed research about saline brines. A comparison of world-wide lithium brines is given by Garrett (2004). Boschetti *et al.* (2007) describes the habitat of saline brines including the importance of isotopes. Presentations by Orocobre (2016), and SaltWorks (2017), focus on the facies of saline lakes, and their lithium potential, as well as lithium brine production characteristics.

The Bario salt, produced in the remote highlands of northern Sarawak served an isolated human population, cattle and wild animals alike since unrecorded times. "Salt hunters" (a term used during the reign of the white Rajahs) extracted the salt from the salt spring, by boiling the brine water in a big pot until the salt forms a greyish layer, then collect the salt from the bottom. This process is still followed until today. The salt is dried completely and inserted into bamboo pipes, which are heated over a fire for 24 hours to harden the salt. The final step is wrapping the salt into big leaves for storage in order to keep it dry and safe for the long journey home. The wrapped salt is sold in bamboo cylinders. Naturally brownish grey, Bario salt's colour is intentionally preserved. It is less salty than commercially available alternatives, partly due to the low magnesium content. Nevertheless it is highly sought-after due to its high, natural mineral contents. A commercially available sample is shown in Figure 1.

Figure 1: Bario salt wrapped in bamboo leaves.

Surprisingly, little is known about the origin of the salt and its geochemical composition. Obviously, the presence of salt in a tropical monsoon climate remains an enigma. As shown in Figure 2, salt deposits do not normally occur in monsoon-wet equatorial regions.

In this paper we have attempted to assemble as much openly available information (Geological Survey reports and the internet) and performed a salt brine analysis.

The new data allowed us to place Bario in context with other salt deposits throughout the world (Figure 3), and to postulate potential scenarios of how the salt may have originated. Comparing the composition of salt brines is tricky; concentrations in the literature are shown in mol, wt % or ppm, as cations or dry salt. Measured salt concentrations in salt lakes are not constant, but fluctuate due to occasional rainfall and fluid circulation

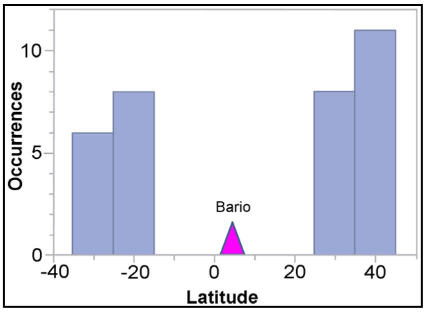

Figure 2: Occurrences of salt lakes, salt springs, and pore fluids are found in desert belts on both hemispheres, and quite often but not always at high altitude. The enigma of the Bario salt is clearly demonstrated by the above template, indicating that evaporites do not occur in tropical-wet climate areas (modified after Warren, 2016). Bario, being located in the vicinity of the equator, is therefore an intriguing anomaly.

(upwelling within the lake-water column). The ratio of the various components, however, may be indicative of a typical salt provenance.

HISTORICAL WORK AND ASPECTS

The Bario area has seen little comprehensive geological fieldwork in recent years, and most concise data are referred to the fieldwork of Wilford (1955) and updated by Haile (1962) (Figure 4). Given that these data are somewhat difficult to come by, we have included for general reading key sections of these old reports below:

Extracted from Wilford (1955):

"Many salt springs occur in the Kelabit Highlands (and the more important ones are shown in Figure 4, and an analysis of the salt is given in Table 1). *The salt is widely used by the local Kelabit people themselves,*

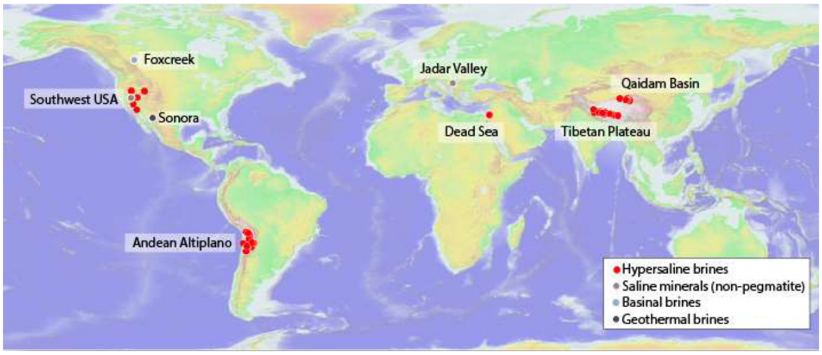

Figure 3: Lithium highland salt deposits in arid settings such as the Andes, Southwest USA and China's Tibetan Plateau (SaltWorks, 2017).

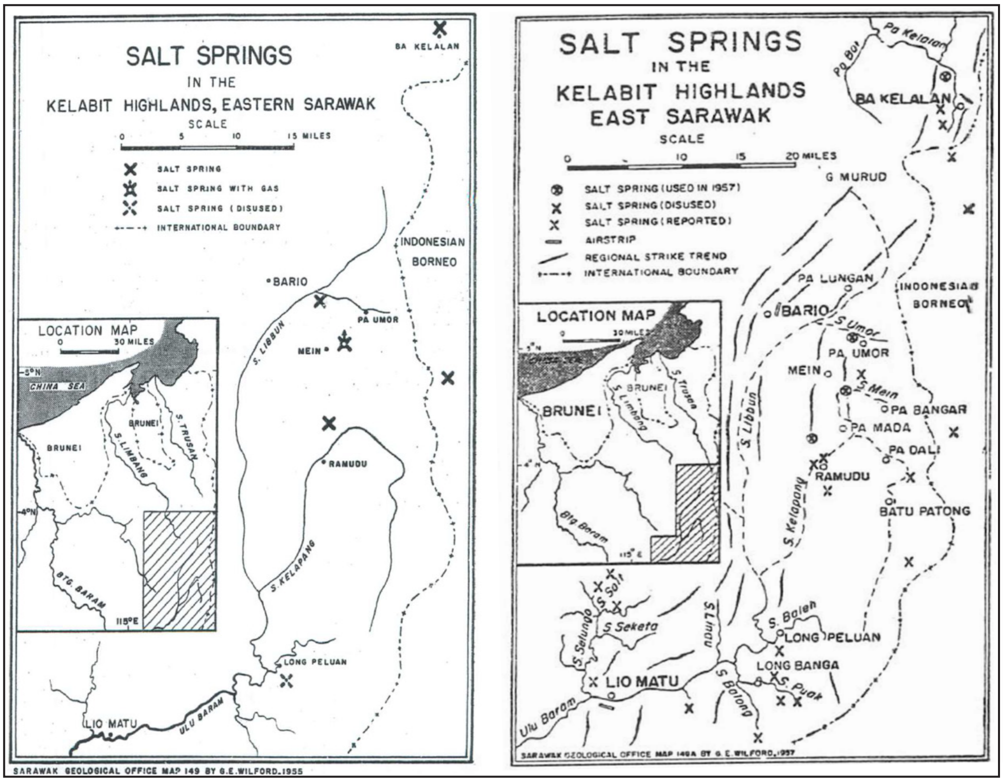

Figure 4: Scanned original maps of the salt spring locations in northern Sarawak from Wilford (1955) on the left, and updated by Haile (1962) on the right. On the left map, one spring is shown to coincide with a gas seep. In the map on the right, historical and abandoned salt springs are shown, plus the strike of the surrounding Rajang Formation rocks.

traded with inhabitants of adjacent lowland areas, and used to feed Kelabit cattle which are said to come to their owners for their salt ration each evening. The amount of salt available is limited as it is obtained from small wells which often become diluted by heavy rain.

The best known springs are those of the Mein River described in 1909 (Sarawak Gazette, 1 March 1909), a small stream running into the Pa Mada, a tributary of the Baram. ' ... We reached the Mein River in the early morning and I was shown several holes where the springs had either dried up or had nearly done so. These latter the Kelabits told me were much resorted to at certain times of the year by large birds, such as herons and storks, who walked about on the marshy ground near the spring drinking the water, apparently a sort of bird Marienbad. The Kelabits take advantage of this habit and, erecting leafy shelters near these springs, and shoot the birds down. We crossed the Mein River, the water of which is only slightly salty, but I was informed that on the occasion of a long drought it gets so salty that the fish all die; then ascending a low hill, we reached the first and largest spring, which belongs to a Kelabit chief called Gali Ballang, and has been worked by him and his ancestors for years and years, in fact as far as the memory of these people can go back. It consisted of a hole about 6 feet square and 4 feet deep, and the water was constantly filtering in through the sides. The water tasted very salty and acidic, though the natives here, by a strange subversion of taste, call it "Mein" which means sweet; "Pun Mein" being therefore "sweet spring" really. We then passed on to the factory, which was a bamboo house of about 60 feet long by 30 feet wide. Here a strange sight presented itself to our eyes, so accustomed to Bornean scenery and industry. The whole of the centre of the hut was taken up by rows and rows of furnaces running length wise and being fed at either end. On these furnaces were numbers of large iron cooking pots of about 4 feet in diameter, each furnace accommodating about 10 pots, which were filled with water from the spring and in various stages of boiling. The method employed is to keep on filling the pots with the water as it is boiled away, during the which process the salt coagulates around the sides of the pot whence it is scooped out and poured into bamboos or bark vessels, which are then thrust into the furnace and kept there until the bamboo, or bark has been burnt off, by which time the salt has solidified and comes out in long cylinders or whatever the shape of the vessel in which it was burnt, four fillings of one of these large cooking pots producing one cylinder of salt about 8 inches long and 3 inches diameter.' ..."

Additional detailed descriptions were also provided by Haile (1962):

"More than 30 salt springs occur in the mountainous country between Lao Miatu and Ba Kelalan which is drained by the headwaters of the Baram and Trusan rivers. Years ago nearly all these springs were worked and there was a flourishing salt-making industry. At that time the salt was more widely traded with people in the adjacent lowland areas, where the supply of imported salt was uncertain due to the effects of piracy on trade. The salt was much preferred to the imported varieties and was quite valuable currency at one time, as Hose (1929, p.191), who was resident in the Baram at the end of last century, records: '. . . this salt . . . has a widespread reputation and was exchanged with the neighbouring tribes for weapons and rubber. It has a reputation as a preventative of goitre . . . I had some analysed in London, and it showed the presence of iodine and lithium.

With the elimination of piracy on the coast imported salt became more generally available and the value of the local salt has since declined. In November 1957 springs at only four places were worked, and three other springs show signs of having been worked in recent years. The salt is mainly eaten by the Kelabit and Murut inhabitants and their cattle, and only small quantities are now traded with adjacent peoples. Some Kelabits work salt springs in Kalimantan.

Quantity of salt produced. As the springs are only worked on demand and by groups of people from different villages it is difficult to estimate the quantities of salt produced. Annual salt production at Pa Mein, the largest spring in the area, is estimated to be of the order of 3 tons and the total for the whole area to be about 5 tons. The annual production in the neighbouring parts of Indonesian Borneo is probably also several tons. The daily production at Pa Mein, when the springs were not diluted by rain water and when 24 iron pans were used night and day, was estimated by G.E. Wilford to be about 100 pounds. There is little doubt that production could be increased considerably if the demand rises but this seems unlikely unless supplies of imported salt are cut off. Improvements could be made in the quality of the salt produced if precautions were taken to prevent contamination of the salt water by ground water and animals; e.g., by the construction of concrete-lined and covered wells.

Quality of salt and chemical analysis. Most salt produced is a grey, buff or off-white colour; the main impurities responsible for the colour are vegetable remains in the salt water, burnt bamboo bark, and rust from iron pans. There is conspicuous variation in taste between the salt from different springs which is readily recognised by the inhabitants and is probably due to the variation in chemical content."

GEOLOGICAL SETTING AND STRATIGRAPHY

The geological setting of the Bario/Kelabit Highlands has been summarised by Wilford (1955), Hutchison (1996, 2005), Ghazally Ismael & Laily Bin Din (1998), among others.

The occurrences of salt appear to be contiguous to the Oligocene to Lower Miocene Kelabit Formation.

This formation is described to comprise of mudstone, sandstone, lignite, thin lenses of impure limestone, and rarely conglomerate beds. It outcrops in the Kelapang tributary of the Puak River that flows into the Ulu Baram River. There appears to be some uncertainty in respect of the said Kelabit Formation, given it is surrounded by turbidite sequences of the Rajang Formation. Could the Kelabit Formation be an allochthonous unit? Its mudstone member(s) are said to be commonly calcareous, sandy and poorly bedded. Its colour is stated to be brownish grey to light bluish grey. The limestone is well bedded. This formation yields fossils that are indicative of both Early Oligocene and Early Miocene ages. The strata are folded around north-south axes. A large number of salty water pools occur throughout the area of mudstone outcrops, suggesting that the mudstone outcrops are hosting the salt springs.

Haile (1962) provided the following additional details:

Lithology: *Mudstone and sandstone are the main rock types, with some lignite and rare conglomerate. The mudstone is commonly calcareous, invariably sandy, poorly bedded, and typically shows spheroidal weathering and conchoidal fracture. The colour is brownish grey or light bluish grey. At many places it contains fragmentary plant remains and pieces of lignite. Nodules and lenses of clay-ironstone and of hard mudstone are common. Sandstone lenses and blocks, mostly 1 to 2 feet across, are common and have a distinctive irregular rather hackly surface. In most outcrops the sandstone is calcareous and pyritic, and at places contains beds and lenses of impure limestone and veins of calcite. A number of salt springs are associated with this mudstone.*

The sandstone is well bedded, and in places contains abundant coalified plant remains and seams and lenses of lignite up to 4 inches thick. This type of sandstone is commonly interbedded with soft, carbonaceous, very sandy black shale, and light-grey mudstone with conchoidal fracture.

Conglomerate are found as boulders at Batu Patong in the Kelapang headwaters, is composed of pebbles up to 2 cm across mainly of red radiolarian chert, vein quartz, sandstone, and agate; the last appears to have been derived from vesicles in a lava without having been rounded to pebbles.

Tectonic aspect: *The formation is moderately to steeply folded along north-south axes, and in general the dips are slightly less steep, and the folding more regular and less chaotic than those of the Setap Shale or Kelalan Formations. The mudstone is fairly hard, but no slaty rocks have been seen. The exposure at the mouth the Benaleh is unique in that it shows intense tight folding, including small recumbent folds a few feet across.*

Thickness: *As the boundaries are not known no reliable estimate of the thickness can be made. From the width of the outcrops it seems probable that the exposed thickness is at least several thousand feet.*

Boundaries: *Neither the top nor the basal boundary has been discovered. On general structural evidence, and taking into account palaeontology and the regional geology, it seems probable that the Kelabit Formation overlies the Kelalan Formation either conformably or with a slight unconformity. To the west, the formation is probably overlain conformably by the Meligan Formation of the Tamabo Range. West of the Tamabo Range the formation has not been recognised. This is presumably due partly to the general hiatus in deposition in the Oligocene and partly to the lateral transition of the upper part of the formation into Setap Shale Formation.*

Fossils and age: *Fossils indicating both Lower Oligocene (Tc) and Lower Miocene (Te_{1-4}) age have been found in the formation. A specimen of calcareous shale from the Kelapang River at the mouth of the Benaleh tributary was examined by R. Todd.*

In summary, one might conclude the Kelabit Formation might be an allochthonous block within a sequence of shallow marine, transitional marine and fluvio-terrestrial deposits. Some indications of potential submarine volcanism are present, particularly in conglomerates. The Kelabit Block appears to be enveloped by deep marine turbidite sequences of the Rajang Formation. Perhaps the Kelabit Block belonged to an eastern Oligo-Miocene shelf, and was transported as a nappe westwards until it came to rest upon the anchi-metamorphic Rajang Formation. The Kelabit Block may equally be interpreted as a large size olistostrome.

BARIO SALT SPRINGS AND SALT HABITAT (CITATION OF GHAZALLY ISMAEL & LAILY BIN DIN, 1998)

"The origin of the salt is not known but the springs occur in a belt parallel to the regional strike of the rocks in this region. A saltmarsh east of Bario at Pa' Umor, which lies in the above belt, was examined to determine the mode of occurrence of the salty water. The saltish water was observed to occur in swampy ground.

No source was observed and the water thus seems to seep to the surface from below. No rock outcrop was seen at the surface in the vicinity of the swamp which occurs in the soil cover of the area.

Various explanations for the occurrence of the salt have been put forward. It has been postulated that the salt sources and water is probably derived from salt bearing beds from the subsurface rocks in the region - and Jordi (unpublished report of Sarawak Oilfields Ltd.) records that near another salt spring, at a place called Ba Kelalan, a rhythmic alteration of sandstone, siltstone and shale occurs which contain concretions of pyrite and gypsum, which can be the probable source of salts in that area. Another hypothesis to explain the source of salt is offered here. Clay-sized particles when laid down in a marine and brackish environment have very high porosity due to their being laid down in a flocculated condition, i.e., the particles are arranged in clumps - a 'card house' structure with edges of particles attracted to faces. When

Table 1: Brine analysis in percentage, published by Wilford in 1955.

		Percent
Sodium	Na	37.61
Potassium	K	0.26
Calcium	Ca	0.90
Strontium	Sr	0.19
Barium	Ba	0.10
Magnesium	Mg	not detected (less than 0.01)
Chlorine	Cl	57.28
Iodine	I	0.052
Vromine	Br	not detected (less than 0.01)
Fluorine	F	0.013
Sulphate	SO_4	not detected (less than 0.01)
Borate	B_4O_7	1.77
Carbonate	CO_3	1.49
Phosphate	PO_4	trace, less than 0.01
Silica	SiO_2	0.12
Iron and aluminium oxides	Fe_2O_3 and Al_2O_3	0.055
		99.84

	Percent
NaCl	94.08
KCl	0.50
$Na_2B_4O_7$	2.30
$CaCO_3$	2.25
$SrCO_3$	0.32
$BaCO_3$	0.14
KI	0.068
SiO_2	0.120
$Al_2O_3 + Fe_2O_3$	0.055
	99.83

the clay is above sea level and is exposed to freshwater moving through it the salt in the pore fluid is removed."

BARIO SALT COMPOSITION (WILFORD, 1955)

The salt's composition is summarised in the following Table 1.

These results can be re-calculated to compounds present in the sample dried at 300 °C (Haile, 1962).

The sample contains potassium iodate, $Al_2O_3 + Fe_2O_3$ are probably clays.

The sample did not exhibit any detectable radioactivity. Nitrates, nitrites and ammonium salts were not detected. A considerable amount of water-insoluble matter was present, amounting to 2.68 % of the dried salt. This is included in the above analysis and consists mainly of carbonates of calcium, strontium and barium.

The presence of an appreciable quantity of borate (2.3% $Na_2B_4O_7$) is noteworthy. This is probably present in the original sample as borax, $Na_2[B_4O_5(OH)_4].8H_2O$. The difference in water content is likely due to the heating of the salt during the drying process. Equally noteworthy is the extremely high Na content (94.08% NaCl). In contrast, inland salt lakes studied by Orocobre (2016; Chile, Argentina, Bolivia, Nevada) and Boschetti *et al*. (2007; Salar de Atacama, Chile) have fairly low Na.

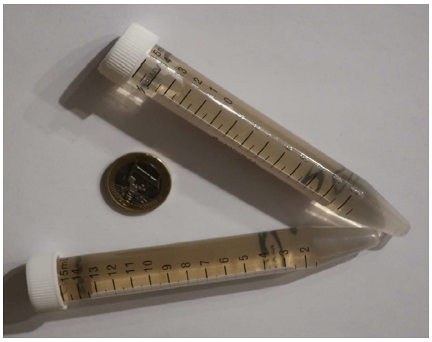

Figure 5: Salt brine samples ready for dispatch to the lab for compositional analysis.

Haile (1962) also mentioned the presence of lithium in the salt, however there is no quantity mentioned. A packed Bario salt bottle, sold in a Miri supermarket some 10 years ago, also mentioned lithium as part of the composition. To verify this and other compositional aspects we therefore carried out a new analysis.

2019 SALT COMPOSITION ANALYSIS

Sample preparation procedure

- Some 50 g of Bario salt was cut from the cucumber-shaped salt stick, and the leave cover removed;
- The salt is a commercially available commodity and packed in Miri, Sarawak (Figure 1);
- The salt looks greyish, its taste being is indeed salty, however with a strong bitter aftertaste;
- Heated to above 300 °C to remove moisture and crystal bound water; (300 °C such that the new analysis can be compared to Wilford, 1955);

- Preparation of a primary brine sample of 60 ml with 5 g dissolved salt;
- Filtering of the primary brine, 0.08 g of dark silty solids (= 0.016 %) were removed;
- The filtered brine looked dark yellow-brown, and was divided in two test tubes of 15 ml content each, containing 1.246 g salt (Figure 5);
- The samples were packed and sent to a specialised water laboratory in Germany for compositional analysis.

INTERPRETATION OF ANALYTICAL RESULTS

Wilford (1955) data and the new analysis are very similar (Table 2). The analysed data point to the presence of key components, which could help to explain where the source of the salt is located, as summarised below:

- Borate (B_4O_7): The high content points to phreatic steam eruptions. Boric acid, or sassolite, is found mainly in its free state in some volcanic districts, for example, in the Italian region of Tuscany, the Lipari Islands and the US state of Nevada. In these volcanic settings the borate is seen to emanate, in phase with steam, from fissures in the ground.
- Lithium (Li): The presence of lithium points to a volcanic or plutonic source, and enrichment in either super arid climate or, alternatively, the former presence of volcanic to phreatic vents.
- Strontium ($SrCO_3$): Strontianite, a typical hydrothermal gang mineral.
- Barium ($BaCO_3$): Witherite, forms in low temperature hydrothermal environments. It is commonly associated with fluorite.
- Fluorine (F): See above.

Table 2: Results of the Bario salt analysis (2019).

Macro-Elements

Element	Analysis
Na	27910.00 mg/l
Ca	127.00 mg/l
Mg	199.00 mg/l
K	105.00 mg/l
Br	50.00 mg/l
B	3356.00 mg/l
Sr	7.82 mg/l
S	6.11 mg/l

Ba-Group

Element	Analysis
Ba	4571.00 µg/l
Be	0.00 µg/l

Si-Group

Element	Analysis
Si	4992.00 µg/l

Li-Group

Element	Analysis
Li	7863.00 µg/l
Ni	0.00 µg/l
Mo	0.00 µg/l

I-Group

Element	Analysis
V	2.26 µg/l
Zn	0.00 µg/l
Mn	27.00 µg/l
I	8014.00 µg/l

Fe-Group

Element	Analysis
Cr	18.00 µg/l
Co	0.00 µg/l
Fe	363.00 µg/l

Nutrient-Group

Element	Analysis
P	1036.00 µg/l
PO4	3.170 mg/l

Element	Analysis
Hg	0.00 µg/l
Se	0.00 µg/l
Cd	0.00 µg/l
Sn	0.00 µg/l
Sb	39.00 µg/l
As	0.00 µg/l
Al	135.00 µg/l
Pb	0.00 µg/l
Ti	13.00 µg/l
Cu	13.00 µg/l
La	0.00 µg/l
Sc	0.00 µg/l
W	0.00 µg/l

- Phosphate (PO_4): Non-diagnostic, could be contamination.
- Iodine (I): Typically found in salt brines and caliche, but also in escaping oilfield brines, in combination with other geological parameters such as tectonism and volcanism (Özdemir, 2018) (Figure 6). This view needs to be further explored given that at least one Bario salt spring coincides with an active gas seep.
- Absence of typical marine salt constituents in the old analysis: Magnesium (Mg), Sulphate ($S0_4$), Bromine (Br); some Mg was found in the new analysis, but hardly any SO_4.

CATION RATIOS

- **Sodium to Lithium Ratio.** Dezayes *et al.* (2015) could prove on examples of several salty springs in the Rhine Graben a temperature relationship between sodium and lithium cation contents in the respective brines (Figure 7). Hot brines tend to be strongly enriched in lithium, whilst relative cool springs such

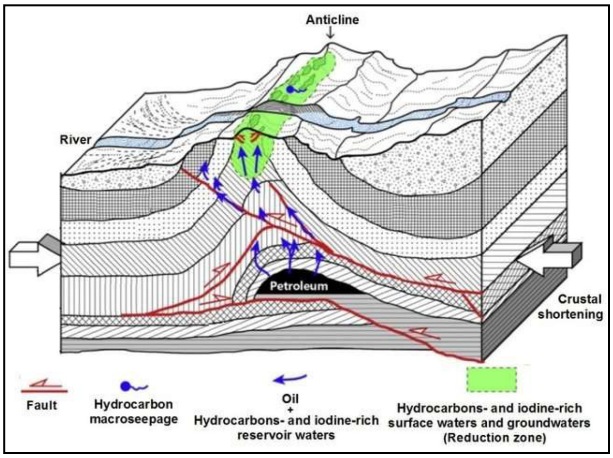

Figure 6: Model by Özdemir (2018) for iodine-rich brines escaping from folded and thrusted rock hosting hydrocarbons.

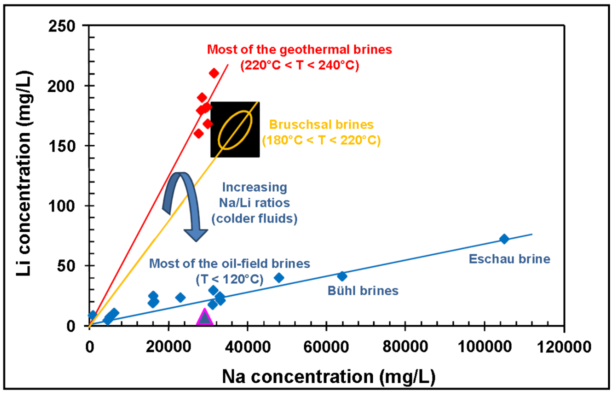

Figure 7: Sodium and lithium concentrations in thermal springs, oil-field brines, and related temperature trends in Rhine Graben Area; this in comparison with Bario, a low-temperature brine (blue triangle). Hot brines generally contain more lithium (modified after Dezayes *et al.*, 2015).

as oilfield brines tend to carry little lithium only. The salty water of Bario is cool, and the observed Na/Li ratio could point to oilfield brine. Averaged sodium to lithium ratios are (from above cited literature): Geothermal brines: 170; Most saline highland lakes: 40-100; Oilfield brines: 1150; Bario: 3580.

- **Lithium to Borate Ratio**. High values of borate and lithium may point to proximity of a hot volcanic/phreatic source, whereas low values in both could be a characteristic for saline lakes without a strong volcanic association. Table 3 shows Bario results in context with highland salts (after Garrett, 2004). A crossplot between Na/Li versus B_4O_7/Li, shows that Bario salt may be compared to some highland salt deposits (Table 3), in particular to the composition of Clayton valley in Nevada (Figure 8).

DISCUSSION: IS THE SOURCE OF THE BARIO SALT AN EVAPORITIC SEQUENCE?

On the first glance, one might feel inclined to treat Bario salt as a derivative of an evaporitic sequence as suggested by Hutchison (1996), with the view that the salty brine used for salt productions stems from a salt-bearing sequence in contact with shallow aquifers, hence resulting in salty groundwater. However, there are two important arguments against this interpretation:

1. In the tropical rainforest climate of Bario, a near-surface salt deposit would not last very long, and there seem to be no indications of dissolution cavities (dissolved salt, gypsum, etc.) in the ground. Some gypsum has been mentioned by Wilford (1955) and Ghazally Ismael & Laily Bin Din (1998), but it seems to be very localised and thin-bedded.
2. The original chemical analysis shown by Wilford (1955) found no sulphate, whereas the 2019 analysis showed 6.11 mg/l sulphur. If the Bario brine would be a product of groundwater leaching evaporitic beds, both the level of calcium and sulphur should be considerably higher. Given the elevated contents of borate and lithium, one might consider Bario as a highland salt that was formed under extremely arid condition in the shadow of high mountain ranges. However, there are also some locations in the world, where similar lithium/borate spring deposits are

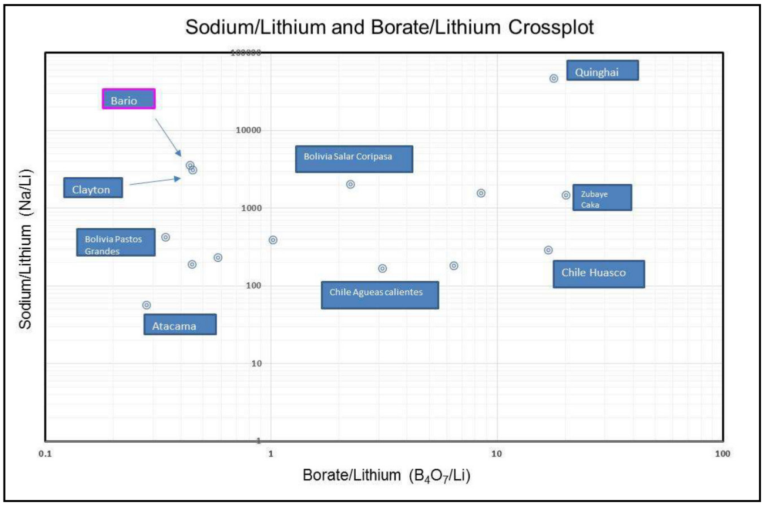

Figure 8: Bario and highland salts in light of borate and lithium contents.

Table 3: Bario in comparison with other lithium and borate salt brines.

Locality	ppm sodium	ppm potassium	ppm lithium	ppm borate	Borate to Li ratio	Na to Li ratio
Bario (Wilford, 1955)	370610			17700		
Bario 2019	27910		7.8	3.4	0.44	3578
Bolivia Salar Hombre Muer	100000	5190	521	233	0.45	191
Bolivia Salar Uyumi	82000	7200	349	204	0.58	234
Bolivia Salar Empexa	67000	30000	172	176	1.02	389
Bolivia Salar Coripasa	710000	120000	350	786	2.25	2028
Bolivia Pastos Grandes Hotspring	770000	89000	1800	608	0.34	427
Chile Aguas Calientes	25460	1183	152	474	3.12	167
Chile Atacama	91000	23600	1570	440	0.28	57
Chile Huasco	38000	10000	130	2200	16.90	292
Tibet Zubaye Caka	720000	16600	489	9900	20.20	1472
China Quaidam	56300	4400	310	2000	6.45	181
China Qinghai lake	39300	1600	0,84	15	17.80	46785
China Mahai	80000	1600	51	434	8.50	1568
Clayton Valley Brine USA	620000	80000	200	90	0.45	3100

Table 4: Types and origins of lithium deposits (Warren, 2016 and SaltWorks, 2017).

Deposit type	Source	Brief description	Typical grade	Examples
Pegmatites	**Magmatic fluids**	Coarse-grained igneous rock formed during late-stage crystal-lisation of magmas	1.5-4% Li_20	Greenbushes, Australia; North Carolina, USA; Bikita, Zimbabwe
Hectorite	Saline brine	Lenses of saline lacustrine smectite clay in association with volcanic centres	0.4% Li_20	Kings Valley, Nevada, USA; Sonora, Mexico
Jadarite	Saline brine	Hydrothermally-altered boro-silicates in sediments of an enclosed saline lacustrine basin	1.5% Li_20	Jadar, Serbia
Continental	Saline brine	Salt pans or salars in enclosed basins with lithium enrichment likely to be from hot springs	0.04-0.15% Li	Clayton Valley, USA; Salar de Atacama, Chile; Salar de Hombre Muerto, Argentina
Geothermal	Saline hydro-thermal brine	Elevated levels of lithium con-tained in steam at geothermal power stations	0.01-0.035% Li	Salton Sea area, California, USA
Oilfield	Basinal saline brine	Elevated levels of lithium contained in waters or brines produced in oilfields	0.01-0.05% Li	Smackover oilfield, Arkansas, USA Foxcreek, Canada

reported, yet without a prominence of evaporates. A classification of lithium salt and borate deposits by Warren (2016) is summarised in Table 4.

Another potential analogue may be the Jadar deposit near the town of Loznica in Serbia (SaltWorks, 2017). It is a prominent lithium deposit in addition to an inferred resource of boron minerals. Jadarite has so far only been identified in significant amounts within the 20 km long Jadar Basin of Serbia, which is similar in size as the Kelabit Block, and entrains oil shales, dolomicrites, pyroclastic sediments and evaporates. These deposits are believed to have been accumulated in an intermontane lacustrine environment. Jadarite is likely formed *via* a hydrothermally-facilitated interaction between saline brine and clastic/evaporitic sediment, either in a tuffaceous or clay host. It is possible that the host mineral for the Bario salt might be colemanite (secondary mineral after borax) or jadarite (a Na, Li, B silicate), which decompose in the groundwater realm and by doing so creates the brine.

Orocobre (2016) suggested the high Lithium content by reaction of hydrothermal fluids with volcanics or simply leaching of volcanics at lower temperature. A high sodium content has been reported in a number of cases and could be an indication for marine influences as in the case of Chaxa Lagoon (Salar de Atacama) or leaching of marine salt deposits.

Wilford's older map shows a gas seep that coincides with a salt spring (Figure 4), and there might be an association between the Bario salt springs and hydrocarbon-bearing rock. This said, with only very little fieldwork data and even less geochemical samples, the jury is still out for the best explanation of the salt´s host rock and the origin of the salt itself.

CONCLUSIONS AND FURTHER WORK

The new analysis completes and corroborates the Wilford (1955) results. Bario salt is a likely non-marine salt of yet unknown origin. It contains significant amounts of lithium, borate, and iodine as well as a marked presence of strontium, barium and antimony. The new analysis, in context with older salt spring data has made a comparison with other equally non-marine salts possible. The presence of borate and lithium points to potential affinities with both non-marine highland salts from those found in Argentina, Bolivia, Nevada and Tibet, as well as with phreatic brine salt of the Jadar deposit in Serbia. The Bario salt contains little sulphur; further work should try to clarify whether or not the sulphur is related to minerals such as gypsum, or has originated from oxidation of pyrite. The calcium concentration is lower than in normal sea water, the Bario salt is therefore unlikely to have been derived from leaching evaporite-bearing sediments in the subsurface as has been suggested by earlier authors.

Clearly, there is a lack of data in almost every aspect. Whilst we are in no way critical of the fieldwork of the 1950's to 1960's, there should be more fieldwork conducted and more salt deposits, as well as brines analysed in northern Sarawak to provide a better understanding of their geochemical composition including several elemental ratios for a provenance study. It is noted that concurrently, a research study on salt brine samples is being conducted by a Masters student at Curtin University Malaysia. Based on additional data, it will be interesting to see, if the Bario salt can be put in comparison with other highland salts. We need to understand where the sources of both borate and lithium are located, and if the lithium content is sufficient for economic exploitation. Furthermore, a stable isotope analysis especially for barium could potentially help to unravel the origin of the Bario salt.

Interestingly, an earlier medical research article by Zaleha *et al*. (2002) has shown a correlation between high cognitive ability of Bario school children compared to other isolated communities due to their intake of Bario salt, which has high micronutrients, especially iodine. The relative high content of iodine might also point to an association of the Bario springs with hydrocarbon-bearing reservoir.

Finally, is the Bario salt production, which has been going on for an unrecorded time, sustainable for an economic extraction of lithium? Will it help to continue support the iodine requirements of the local population? We believe there is a call for further action to address these questions.

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